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Environmental Effects of Dredging Technical Notes

GUIDE TO SELECTING A DREDGE FOR MINIMIZING RESUSPENSION OF SEDIMENT

PURPOSE: This technical note contains assessments of conventional and special-purpose dredges in removing sediment with minimal sediment resuspension. If sediment resuspension is a critical factor in dredging areas of contaminated material, the following guidance will aid in specifying the dredge and operating conditions.

BACKGROUND: Investigations were conducted as part of the Corps of Engineers' Improvement of Operations and Maintenance Techniques (IOMT) Research Program to evaluate the resuspension of sediment into the water column due to dredging operations. Laboratory, field, and literature studies have been used to define the sediment resuspension characteristics of most conventional and several special-purpose dredges. The natural hydrophobic tendency of most organic contaminants and the high sediment-sorptive capacity for inorganic contaminants limits release to the soluble forms and makes the simple measure of sediment resuspension during dredging a relative measure of the potential for contaminant release.

DEFINITION OF SEDIMENT RESUSPENSION: For the purpose of this technical note, the sediment resuspension caused by a dredging operation is defined as those sediment particles resuspended into the water column during the dredging operation that do not rapidly settle out of the water column following resuspension. This includes any resuspension by barge or hopper overflow, spillage, leakage, spud movement, or other contributors directly related to the dredging operation. Contributions of sediment from the prop wash by tenders, barge movement, or other operations not directly involved in the dredging operation are not considered in this definition. The method of disposal was not considered in evaluating the sediment resuspension or in the rating of various dredge types.

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Approach

The results were derived from suspended solids measurements from discrete water samples taken at various depths in the water column at field study sites. The trends observed at the field sites are shown as suspended solids concentrations (adjusted for background conditions) for three sections of the water column: upper, middle, and lower, each being one-third of the total depth.

Assessment of Resuspension Potential

Conventional dredges

Conventional dredges include unmodified types commonly used in the United States such as hydraulic dredges (e.g., cutterhead, dustpan, and hopper dredges) and mechanical dredges (e.g., the bucket or clamshell dredge). Operational parameters that affect sediment resuspension are discussed, and control measures that may reduce resuspension are presented.

Cutterhead dredges. The popular high-production cutterhead dredge may not seem a very likely candidate for efficient removal of contaminated sediment because of the high-energy cutting and sweeping actions associated with its operation. However, field studies conducted in the James River near Norfolk, Va. (Raymond 1984) and in the Savannah River near Savannah, Ga. (Hayes et al. 1984) indicated that the cutterhead dredge is capable of removing sediment with relatively small amounts of resuspension extending beyond the immediate vicinity of the dredge as compared to other conventional dredge types. Figure 1 gives an indication of typical suspended solids concentrations in a turbidity plume generated by a cutterhead dredging operation.

Research under the IOMT Program has shown that sediment resuspension by a cutterhead dredge can be reduced by proper selection of the cutter rotation speed, ladder swing speeds, and depth of cut. This does not suggest that restrictions should be placed on these parameters to minimize resuspension. In fact, data presented by Hayes et al. (1984) suggest that the optimum selection of these parameters for minimum resuspension generally corresponds to the selection for achieving highest production. So by properly optimizing production, as every dredge operator attempts to do, minimum resuspension will usually occur. The primary exception to this is the practice of undercutting

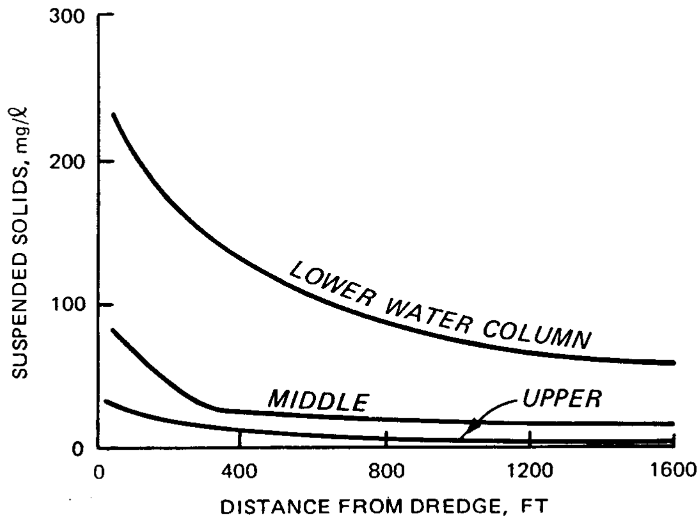

Figure 1. Resuspended sediment levels from cutterhead dredge operations in the Savannah River

to remove large banks of material (i.e., material thickness of 10 ft or greater). This technique involves cutting the bank at near the project depth and allowing the large volume of overlying bank material to collapse into the cutterhead. Overload of suction capacity of the inlet pipe may occur, causing excess sediment particles to be resuspended rather than carried through the pipe. For this reason, excessive submergence of the cutterhead below the sediment line should be avoided.

Dustpan dredges. The dustpan dredge is a hydraulic suction dredge that uses a widely flared dredgehead along which water jets are mounted. The jets loosen and agitate sediment particles, which are then captured in the dustpan dredgehead as the dredge moves forward. This type of dredge works best in free-flowing granular material and is not generally used to dredge fine-grained (clay) sediment. However, in 1982, an experiment was conducted using a modified dustpan head (without water jets) to dredge fine-grained sediment in the James River. A modified dustpan head and a conventional cutterhead were operated in the same reach of the river for comparison. It was hoped that the modified dustpan head using suction only could excavate thin layers of contaminated clay sediment with less resuspension than a cutterhead. Unfortunately, the dustpan head experienced repeated clogging and produced at least as much resuspension as the cutterhead operating in the same material (Raymond 1984).

Hopper dredges. Hopper dredges typically remove sediment by dragging a large flat draghead and using hydraulic suction to remove the disturbed material. Because of the location of the drag arm beneath the dredge, it is difficult to measure the resuspension near the draghead; however, data presented by Hayes et al. (1984) indicated that the resuspension without overflow may actually be less than for a cutterhead dredge.

A hopper dredge can continue to operate beyond the initial filling of the hoppers and discharge overflow from the hoppers into surrounding waters, resulting in a large increase in the turbidity plume. The differences between the turbidity plume generated by overflow and nonoverflow operations are shown in Figure 2. This suggests that some restrictions on overflow may be necessary if a hopper dredge is used for removing contaminated sediment.

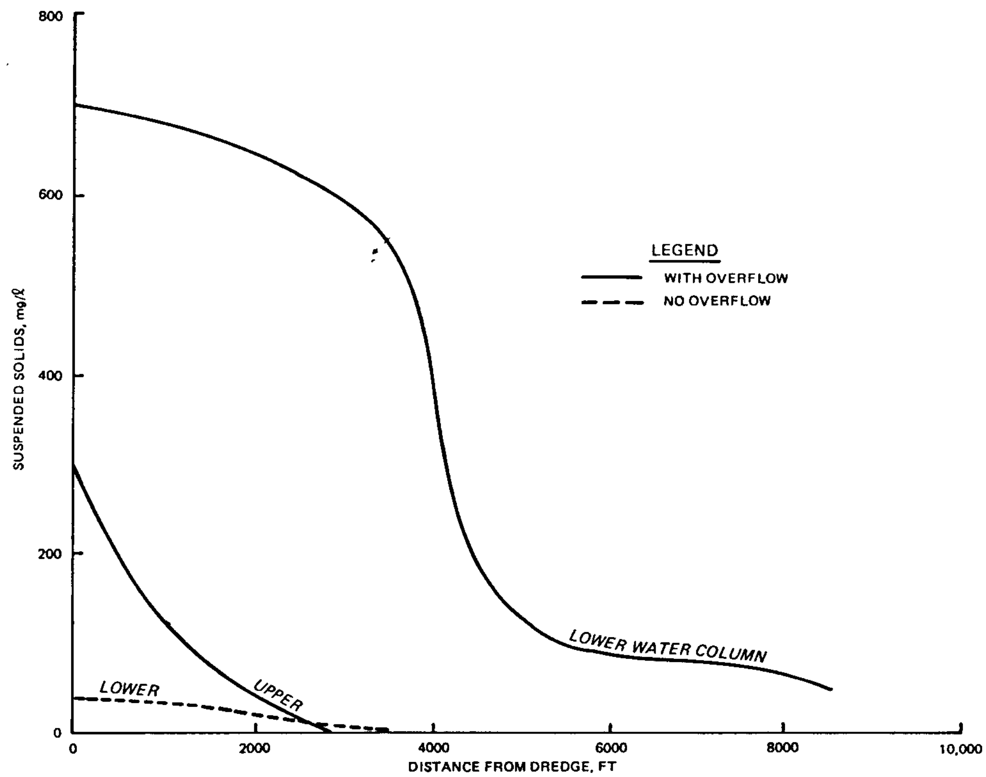

Figure 2. Resuspended sediment levels measured behind the dredge during hopper dredge operations in Grays Harbor with and without overflow

Bucket dredges. Clamshell dredges, the most common type of bucket dredge, are typically used in areas where hydraulic dredges cannot work because of the proximity of piers, docks, etc., or where the disposal area is too far from the dredge site for it to be feasible for a cutterhead dredge to pump the dredged material. Resuspension from operation of open-bucket clamshell dredges is typically higher than that from most cutterhead dredges. This resuspension is generally due to the dynamic impact of the bucket on the channel bottom, the spillage and leakage from the filled bucket, and the washing action of the empty bucket falling through the water column. Resuspension levels of the dredging operation are even higher when the scow is allowed to overflow.

Sediment resuspension from clamshell dredges can be reduced by the use of an enclosed clamshell bucket. This bucket significantly reduces spillage and leakage, which are major contributors to the turbidity plume. Figure 3 shows the benefit of using an enclosed bucket. The operation of the dredge can be modified slightly to reduce sediment resuspension by slowing the raising and lowering of the bucket through the water column. It must be noted that this operational modification reduces the production rate of the dredge.

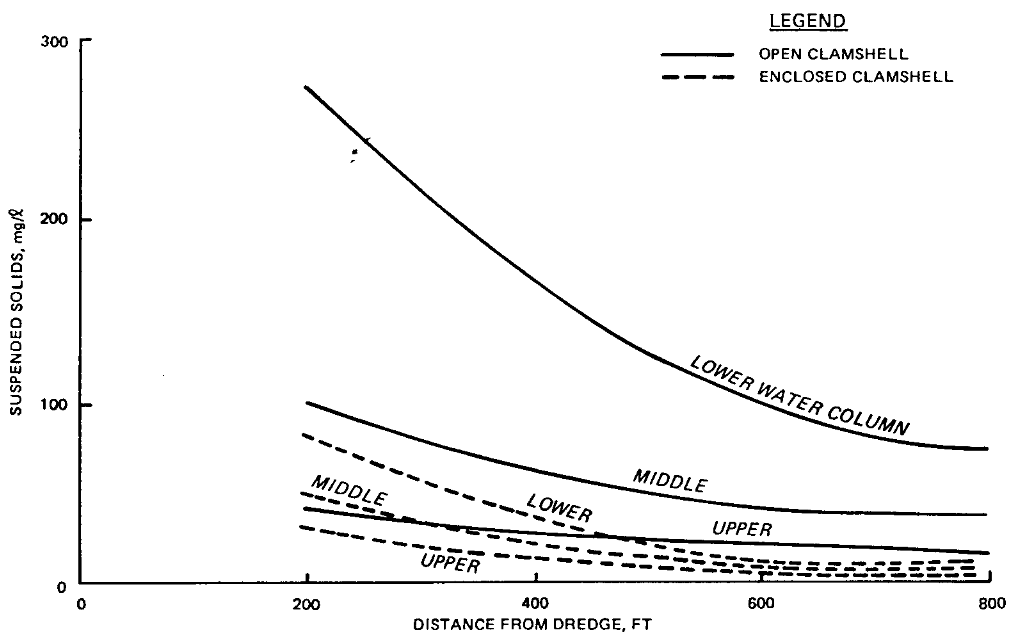

Figure 3. Resuspended sediment levels from open and enclosed clamshell dredge operations in the St. Johns River

Special-purpose dredges

Special-purpose dredging systems have been developed during the last few years in the United States and overseas to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediment. Most of these systems are not intended for use on typical maintenance dredging

Pneuma pump	48 mg/ℓ 3 ft above bottom
	4 mg/ℓ 23 ft above bottom (16 ft in front of pump)
Clean-Up System	1.1 to 7.0 mg/ℓ above suction
	1.7 to 3.5 mg/ℓ at surface
Oozer pump	Background level (6 mg/ℓ) 10 ft from head
Refresher System	4 to 23 mg/ℓ 10 ft from head

* Suspended solids concentrations were adjusted for background concentrations.

Summary

The IOMT research has shown that most conventional dredges can be used to remove sediment with a limited amount of sediment resuspension if they are properly operated and a few precautions are taken or plant modifications are made. This can be accomplished with only a small increase in cost over a normal dredging operation, and typically conventional dredging equipment is readily available. The data show that cutterhead dredges and hopper dredges with no overflow generate less resuspended sediment than mechanical dredges. The following tabulation gives a summary of suspended sediment levels observed during IOMT field studies. However, in many cases, maneuverability requirements, hydrodynamic conditions, location of the disposal site, and other factors may dictate the type of dredge that must be used; the strategy then must be to minimize the resuspension levels generated by that dredge.

If no conventional dredge is acceptable, a special-purpose dredge may have to be selected. These dredges generally resuspend less material than conventional dredges, but associated costs may be much greater. As in the case of conventional dredges, the selection of a special-purpose dredge will likely be dictated by logistics, economics, and availability.

Dredge Type	Downcurrent Distance-Suspended Solids Concentration, mg/ℓ* Within 100 ft	Within 200 ft	Within 400 ft
Cutterhead	25 - 250	20 - 200	10 - 150
Hopper			
With overflow	250 - 700	250 - 700	250 - 700
Without overflow	25 - 200	25 - 200	25 - 200
Clamshell			
Open bucket	150 - 900	100 - 600	75 - 350
Enclosed bucket	50 - 300	40 - 210	25 - 100

* Suspended solids concentrations were adjusted for background concentrations.

Future Developments

Research is being conducted to identify modifications to conventional dredges that may decrease the sediment resuspension to levels nearer those of special-purpose dredges. An example is the matchbox suctionhead tested by the US Army Engineer District, Chicago. The Dutch-developed matchbox suctionhead entrains sediment into the suction pipe of a hydraulic dredge by using the swinging action to force material into a large funnel-shaped opening on one side of the suctionhead and adding water through the other side. Since the suctionhead is symmetrically designed, it will operate during swings in both directions.

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Environmental Effects of Dredging Technical Notes

SEDIMENT RESUSPENSION BY SELECTED DREDGES

PURPOSE: The size and concentration of sediment plumes measured in field studies of selected dredging equipment are described. This information is useful when sediment resuspension must be minimized because of adverse environmental impacts which may include the release of sediment-associated chemical contaminants. The information presented here is intended to supplement and update information given in a previous technical note on the same topic (Hayes 1986a).

BACKGROUND: Dredging operations may be required to comply with in-stream State water quality standards based on maximum allowable concentrations of inorganic and organic compounds. Although the majority of materials requiring maintenance dredging in the United States is uncontaminated, the removal of contaminated sediments (estimated to be less than 10 percent of maintenance materials) poses a serious problem. Hence, a project to study the potential for contaminant release during dredging has been initiated through a field studies program. The field studies described herein were conducted by the Waterways Experiment Station under the Improvement of Operations and Maintenance Techniques (IOMT) research program and in cooperation with other US Army Engineer Districts to evaluate the sediment resuspension characteristics of selected dredges (McLellan et al., in preparation).

The release of hydrophobic (strongly adsorbed) chemicals can be evaluated by examining the transport of resuspended sediments. The release of poorly adsorbed chemicals to the water column is a more complex problem because these contaminants can disassociate from sediment particles. Evaluation of dissolved chemical release at the point of dredging may be more appropriately addressed by laboratory studies, such as elutriate testing (Environmental Effects Laboratory 1976, USEPA/USACE 1977), to evaluate contaminant release in the more biologically available, water phase. The problem of adverse environmental impacts from dredging contaminated sediments has been recognized by the Dutch and the Japanese, who have developed specially designed dredges, which are generally not readily available in the United States, for minimizing resuspension of contaminated sediments.

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Introduction

Dissolved organic and inorganic pollutants in the environment may become adsorbed to sediment particles and, through deposition, form reservoirs of pollutants in bottom sediments. Many pollutants, such as hydrophobic organics (e.g. PCBs) and some inorganics, have a tendency to remain strongly adsorbed to sediments even after mechanical resuspension into the water column as a result of dredging activities. Hence, the resuspension and dispersion of sediment during dredging operations was measured to determine the potential for release of strongly adsorbed chemicals into the water column. Three conventional dredges were examined: hydraulic pipeline cutterhead dredges; hopper/dragarm dredges; and mechanical (clamshell/bucket) dredges. Methods for controlling sediment resuspension from these dredges have been described in other publications (Raymond 1984; Hayes, Raymond and McLellan 1984; Hayes 1986a). These control methods include modification of equipment operation and equipment design.

Scope

Potential sources of sediment resuspension considered here are those directly associated with dredging and material handling equipment. (Sediment resuspension by support craft and from the material disposal operation are not considered in this analysis.) This note considers some methods for control of the dredging operation without major equipment modification to minimize sediment resuspension at the point of dredging. The vertical and horizontal distribution of resuspended sediment from conventional dredges was evaluated by measuring the total suspended solids (TSS) concentration (inclusive of background suspended sediment) at locations throughout the water column. These data are graphically presented in figures later in this note to compare plume size and TSS concentrations between different dredges.

Sampling and Data Analysis

Water column sampling was performed by taking grab water samples throughout the resuspended sediment plume. The TSS levels were averaged over the duration of the dredging project and are presented for 25-, 50-, 75-, and

100-percent sections of the water column depth. Isopleths showing lines of constant TSS concentration were drawn, using an interpolation algorithm to depict plume dimensions in horizontal or vertical sections of the water column.

Results

Cutterhead dredge

The cutterhead dredge is a hydraulic suction pipeline with a rotating cutterhead attached to the suction intake to mechanically assist in the excavation of consolidated material. Mechanical mixing by the rotating cutterhead is a major factor in sediment resuspension by this type of dredge. Cutterhead blades are designed to direct loosened material efficiently toward the suction intake. Efficient operation of a cutterhead dredge and minimization of sediment resuspension can be achieved by proper dredge design and operation. The intake velocity of the suction mouth must be sufficient to remove all of the material excavated by the cutterhead blades, or the excess material will enter the water column. The depth of cut should approximate the diameter of the cutterhead, as overburial of the dredge head tends to result in excessive sediment resuspension. High swing speeds and cutter rotation speeds may also result in excessive sediment resuspension at the point of dredging (Hayes 1986b; Hayes, McLellan, and Truitt, in preparation). Sediment resuspension from cutterhead dredges is chiefly in the lower portion of the water column. Figure 1 shows plume TSS concentrations measured at the Calumet Harbor project. Plume TSS concentrations at 100-percent depth are twice as high as those measured in the upper 25 percent of the water column.

Hopper/dragarm dredge

Hopper/dragarm dredges are seagoing vessels that trail a hydraulic suction line and draghead for removal of bottom sediments. Materials are excavated and pumped through the dragarm into hoppers located in the vessel hull. Hoppers are sometimes allowed to overflow supernatant until the contents are of a high enough density to achieve an "economic load." Hopper overflow may be quite turbid when dredging fine-grained materials that do not settle rapidly in the hopper bins. Aside from possibly requiring rehandling if currents do not move sediments away from the dredging site, overflow of fine materials into the top portion of the water column is highly visible and

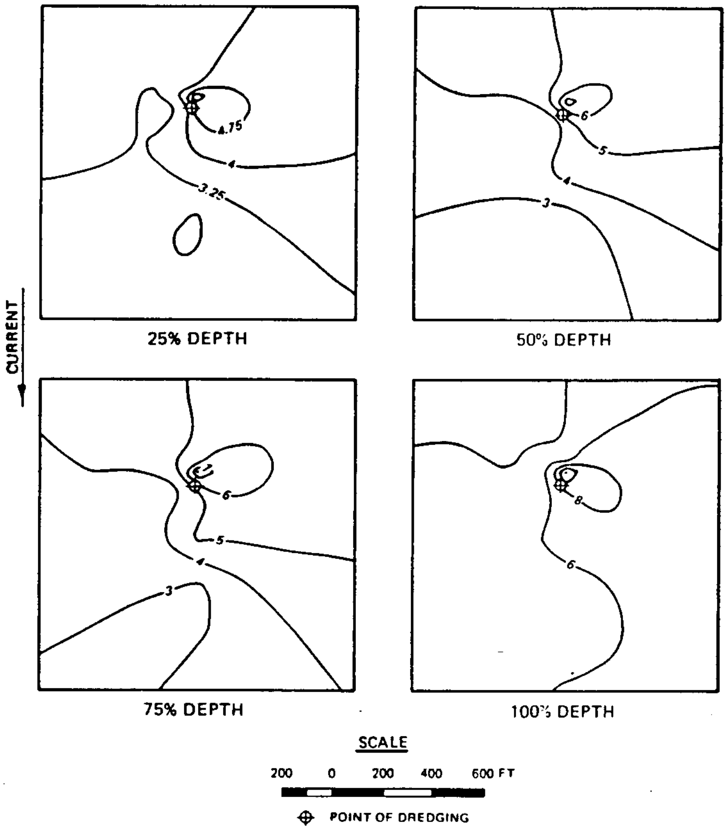

Figure 1. Plan view of resuspended sediment plume caused by a cutterhead dredge at Calumet Harbor; sediment concentration isopleths (milligrams/litre) are shown for 25-, 50-, 75-, and 100-percent depths of the water column. Background TSS concentrations ranged from 2 to 5 mg/ℓ

aesthetically displeasing. If sediments are contaminated, pollution of the water column may be a problem. Figure 2 shows a sediment plume caused by a hopper/dragarm dredge (with overflow) at Grays Harbor, Washington. Sample boats anchored behind the passing hopper/dragarm dredge measured the decay of the sediment plume as a function of time or distance behind the dredge. During dredging with overflow, high TSS concentrations are shown near the top of the column and TSS levels of around 700 mg/ℓ developed near the bottom as the plume settles. Figure 3 shows the resuspended plume caused by the hopper/dragarm dredge without overflow. Plume TSS concentrations are negligible in the upper water column and only 40 to 50 mg/ℓ near the bottom.

Clamshell dredge

A clamshell dredge is a mechanical device operated by a crane and is

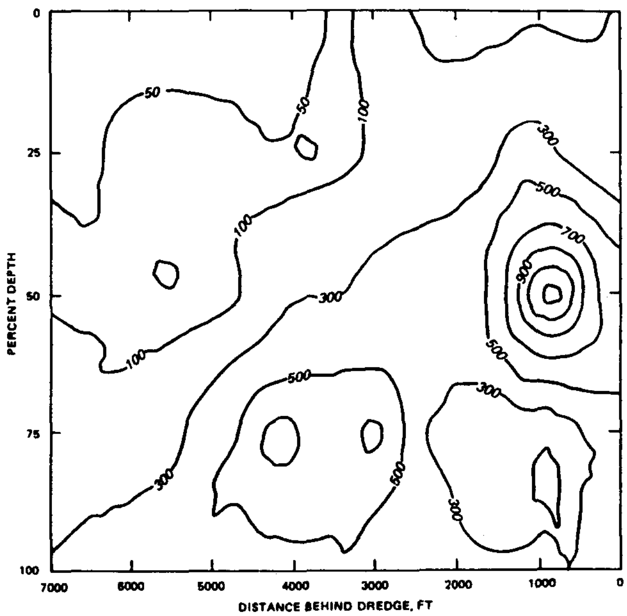

Figure 2. TSS concentration isopleths (milligrams/litre) in a vertical section of the water column directly behind a hopper dredge during overflow operations at Grays Harbor, Washington. Background TSS concentrations ranged from 28 to 60 mg/ℓ

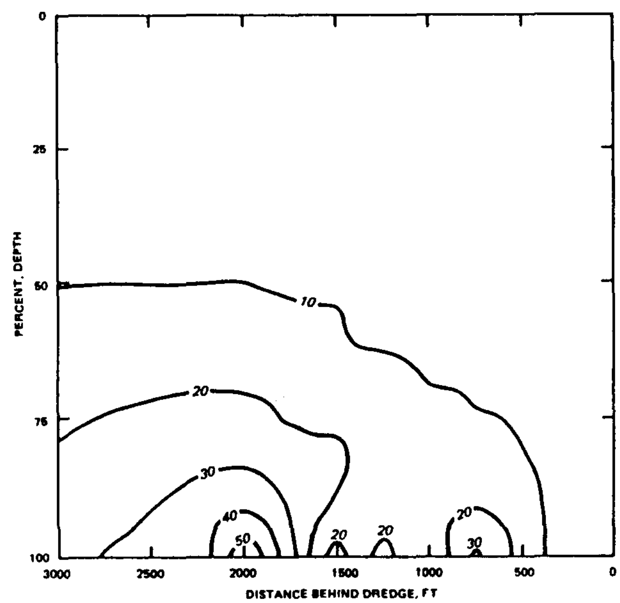

Figure 3. TSS concentration isopleths (milligrams/litre) in a vertical section of the water column directly behind a hopper dredge during nonoverflow operations at Grays Harbor, Washington. Background TSS concentrations ranged from 12 to 54 mg/ℓ

capable of excavating material at near in situ density. Sediment resuspension from clamshell dredges can be controlled, sometimes at the expense of dredge production, through careful operation, such as reducing the speed at which the crane lowers an empty bucket through the water column to pick up a load of sediment, and the rate at which the full bucket is lifted through the water column to remove the excavated material. Limiting the practice of smoothing the excavated area by dragging the bucket along the bottom may also reduce sediment resuspension at the point of dredging. Figure 4 shows a sediment plume caused by a clamshell dredging operation at the Calumet River project. TSS concentrations of 140 mg/ℓ are shown at 100-percent depth due to mixing caused by bucket impact and withdrawal from the bottom. High TSS levels are evident throughout the water column due to erosion and leakage of material from the bucket as it is lifted to the surface. Enclosed clamshell buckets have been designed to reduce erosion and leakage of material into the water column, but they have not been extensively tested.

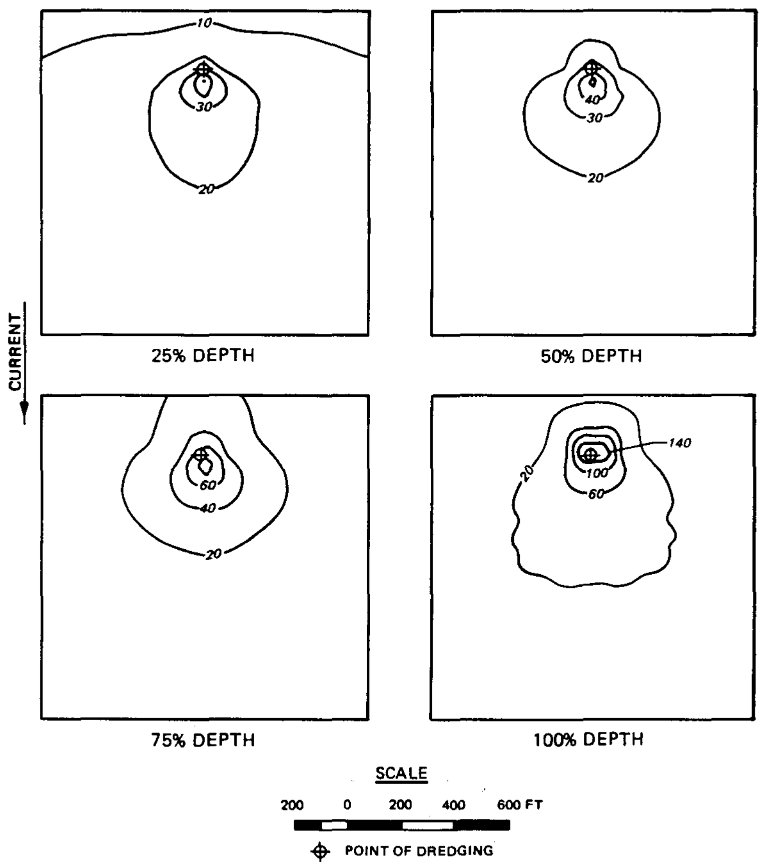

Figure 4. Plan views of resuspended sediment plume caused by a clamshell operation at Calumet River; sediment concentration isopleths (milligrams/litre) are shown for 25, 50, 75, and 100 percent of the water column depth. Background TSS concentrations ranged from 10 to 12 mg/ℓ

Plume comparisons

Results show that the TSS levels from clamshell dredging (Figure 4) are an order of magnitude higher than from cutterhead dredging of similar sediments at the Calumet project (Figure 1). Also, clamshell dredging distributed sediment throughout the water column, whereas the plume from cutterhead dredging remained in the lower part of the water column. It is clear that hopper overflow causes high levels of TSS throughout the water column (Figure 2) and that concentrations are more than an order of magnitude higher than for hopper/dragarm dredging without overflow (Figure 3). Figure 5 is a summary of the worst-case sediment resuspension results from the conventional dredges studied under the IOMT program (McLellan et al., in preparation).

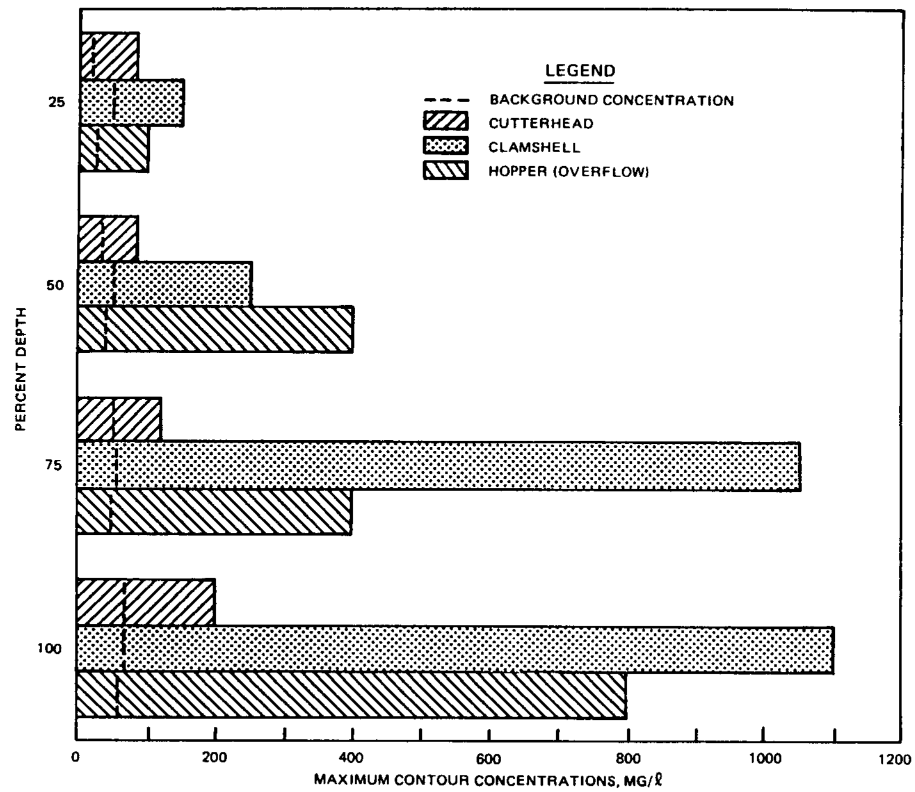

Figure 5. Maximum TSS concentration levels (milligrams/litre) measured for cutterhead, clamshell, and hopper dredges during IOMT field studies

Some dredging operations studied under the IOMT program were not strictly controlled to minimize sediment resuspension, but all sediments were maintenance materials and are therefore similar in that they are unconsolidated and composed of relatively fine particles. Nevertheless, the field study results were consistent in showing the cutterhead dredge to cause significantly lower TSS concentrations than the hopper/dragarm dredge, with overflow, followed by the clamshell dredge.

Conclusions

The size and concentration of sediment plumes show the potential for the release of strongly adsorbed pollutants into the water column by particular dredges. Figure 5 is useful for evaluating dredge types in applications where materials are contaminated, or when sediment resuspension may have a negative impact on the environment. The cutterhead dredge is a logical selection for controlling sediment resuspension while maintaining efficient production. In applications where a cutterhead dredge is not practical (i.e., for work in open seas with significant wave heights (over 3 ft), when a hopper/dragarm dredge would be preferred, or around docks and other harbor installations where a clamshell dredge would be preferred), sediment resuspension from clamshell and hopper dredges can be controlled through control of the dredging operation. Accordingly, limiting overflow from hopper/dragarm dredging (Figure 2) showed significant benefits by reducing water column TSS levels to near background levels compared to the water quality conditions during hopper overflow (Figure 2).

Future Directions

Plume sizes and concentrations are useful in estimating the relative merits of different dredge types for the control of sediment resuspension. Future research efforts in this area will be to collect data for estimating the mass rate of sediment resuspension (kilograms/second or kilograms/cubic metre) for a particular dredge type under a given set of project conditions. This information is useful as input for and in development of predictive models for evaluating the potential environmental impact of sediment resuspension and contaminant release during dredging. Modifications of the laboratory elutriate test will be investigated as a tool for use in conjunction with sediment resuspension models to estimate the release and distribution of the more biologically available, soluble pollutants.

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Environmental Effects of Dredging Technical Notes

A PRELIMINARY EVALUATION OF CONTAMINANT RELEASE AT THE POINT OF DREDGING

PURPOSE: The purpose of this technical note is to present a preliminary evaluation of the standard elutriate test as a predictor of contaminant release (dissolved form) to the water column at the point of dredging. This note is meant to extend previous notes (Hayes 1987, Havis 1987) which dealt with resuspension of sediments due to dredging and the release of adsorbed chemicals which could enter the water phase at the point of dredging.

BACKGROUND: Data collected under the Dredged Material Research Program (DMRP) showed that the standard elutriate test (Keeley and Engler 1974, US Environmental Protection Agency and US Army Corps of Engineers 1977, Environmental Effects Laboratory 1976) predicted, within an order of magnitude, dissolved chemical concentrations in water at dredged material disposal sites (Jones and Lee 1978). The potential for contaminant release also exists, however, at the point of dredging. This source of contaminant release during dredging was investigated by McLellan et al. (in preparation) under the Improvement of Operations and Maintenance Techniques (IOMT) program. Because of the success of the standard elutriate test for simulating dissolved contaminant release at the disposal site it was investigated as a tool for predicting contaminant release at the point of dredging.

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Introduction

Most of the sediments dredged to maintain the nation's navigation projects are clean, and the water quality impacts of dredging these clean sediments involve the temporary effects of turbidity caused by resuspended sediments. Although it has been estimated that less than 5 percent of the nation's maintenance materials are considered unacceptable for unconstrained open water disposal, the potential impacts of dredging in these sediments may involve toxicity from heavy metals and the effects of carcinogenicity and bioaccumulation from xenogeneic (man-made) organics such as polychlorinated biphenyls (PCBs). Developing methods for predicting the potential for contaminant release at the point of dredging is important to assure that dredging operations comply with state in-stream water quality standards where appropriate and to minimize potential adverse effects to aquatic systems.

Contaminant release at dredged material disposal sites has been studied under the DMRP effort, and preliminary work to describe contaminant release at the point of dredging has been done under the IOMT program. Work in the DMRP showed that chemical analysis of the bulk sediment is not appropriate for predicting the release of dissolved chemicals to the water column (Lee and Plumb 1974). Chemical release to the water column could be better evaluated by using a test that simulated the physical/chemical processes occurring in the field (Keeley and Engler 1974). These processes include the resuspension and mixing of sediment in the overlying water, subsequent settling of larger particles, and the gradual deposition of silts and clays. During the resuspension and settling process, however, chemicals that were sorbed to sediment particles may desorb into the water column.

Mechanisms for desorbing chemicals that then remain soluble are more complex than for chemicals that are strongly adsorbed to sediment particles. These particles are then quickly removed from the water column by gravity. Dissolved contaminants may be removed from the water column by mechanisms such as adsorption onto sediment particles which settle to the bottom, precipitation processes, redox transformations, uptake by aquatic life, degradation, and volatilization. Hence, because of the potential for dissolved chemicals to reside in the water column for a long period of time and the rapid availability of these contaminants to aquatic life, a predredging laboratory test such as the elutriate test may be necessary to evaluate the potential for dissolved chemical release at the point of dredging.

Methods

Standard elutriate test

The original elutriate test (Figure 1) (*Federal Register* 1973a, 1973b) was modified (*Federal Register* 1977, US Environmental Protection Agency and US Army Corps of Engineers 1977) to include the use of forced air for mixing. Standard procedures for the test specify that 20 percent by volume of undisturbed sediments be mixed with 80 percent by volume of water from the dredging site. Agitation by mechanical mixing for 1/2 hr and release of compressed air through a diffusing stone simulates mixing and aeration by hydraulic pipeline dredging. The mixture is allowed to settle for 1 hr. The supernatant is collected and filtered through a 0.45-micron filter and analyzed for chemicals of concern.

Field work

The data presented in this note were taken from four dredging sites located at Black Rock Harbor, near Bridgeport, Conn.; Calumet Harbor, near Chicago, Ill.; the Duwamish River, near Seattle, Wash.; and the James River, near Jamestown, Va. These data were obtained as a part of the larger IOMT

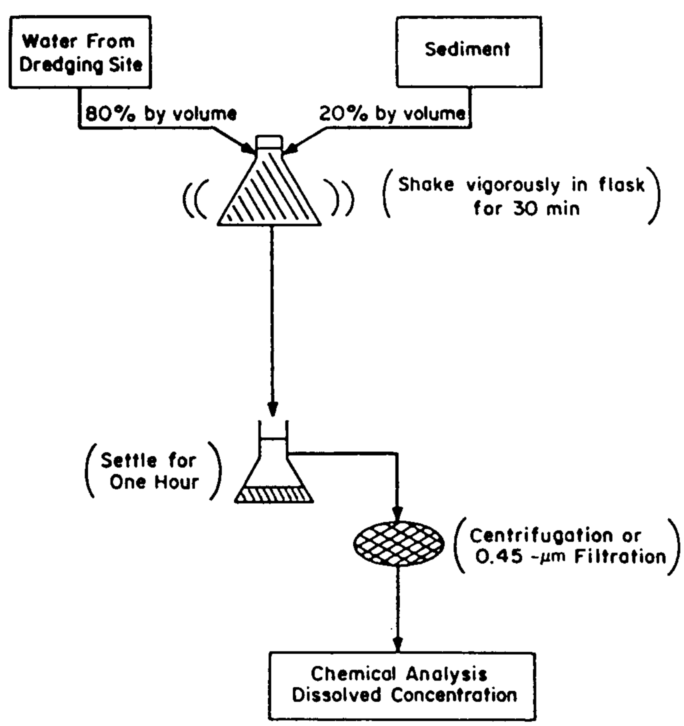

Figure 1. Standard elutriate test

data collection effort to characterize the sediment resuspension and contaminant release characteristics of selected dredges (McLellan et al., in preparation). Table 1 summarizes the conditions at the field sites and the types of dredging equipment used.

Evaluation of the standard elutriate test predictions

Predredging sediment samples were taken in the dredging area for laboratory analysis by the standard elutriate test. During dredging, samples were taken near the bottom of the water column for chemical analysis of soluble (<45 mm) forms. The samples were taken within a few feet of the operating dredge head in the case of hydraulic dredging and within 50 ft of the dredge in the case of mechanical dredging. The dissolved chemical concentrations measured in the water column near the dredge were compared with the corresponding concentrations measured in samples obtained from standard elutriate tests.

Results

Black Rock Harbor

Sediment sampling for elutriate testing was conducted on 2 May 1985, and water-column sampling during the clamshell dredging operation was conducted on 5 and 6 May 1985. Figure 2 shows the results of chemical analyses on dredging site water-column samples and standard elutriate test samples. The average values shown represent means of three measured chemical concentrations. Where equal values (equal-length bars) are shown for water column and elutriate test results, as is the case for cadmium and arsenic, the chemical concentrations were too low for the instrumentation to detect and therefore the instrument detection limit is shown.

The elutriate test predicted within one order of magnitude the chemical concentrations measured in the water column at the dredging site (Figure 2). Chemical species of metals were predicted best and total phosphorus and the ammonium ion (NH_4^+) were predicted with less accuracy. Based upon these results, the standard elutriate test is a conservative predictor of chemical concentrations at this dredging site since laboratory values were consistently higher than those measured in the field water-column samples.

Table 1

Summary of Field Site Conditions

Study	Dredge Plant	Site Conditions	Sediment Characteristics	Current Range ft/sec	Background Total Suspended Solids (TSS) Concentration mg/ℓ		Maximum TSS/ Background TSS
					Surface	Bottom	
Black Rock Harbor	Open Clamshell ($10\ yd^3$)	Estuary (10-21 ppt)	Sandy, organic clay 90% fines, LL = 170 PI = 65	0.2-0.8	45	69	15.9
Calumet Harbor	Cutterhead (12-in)	Freshwater lake	Soft organic clay/ silt, OH, 80% fines sp gr = 2.71	0-0.2	2	5	2.0
Duwamish Waterway	Open clamshell	Estuary (12-21 ppt)	Sandy clayey silt (MH)	0.3-1.1	11	26	6.1
James River	Cutterhead	Estuary	Silty clay (CH) LL = 120, PI = 80	0.5-2.3	42	86	3.8

Note: LL = liquid limit; PI = plasticity index; and sp gr = specific gravity. Soil classification is by the Unified Soil Classification System.

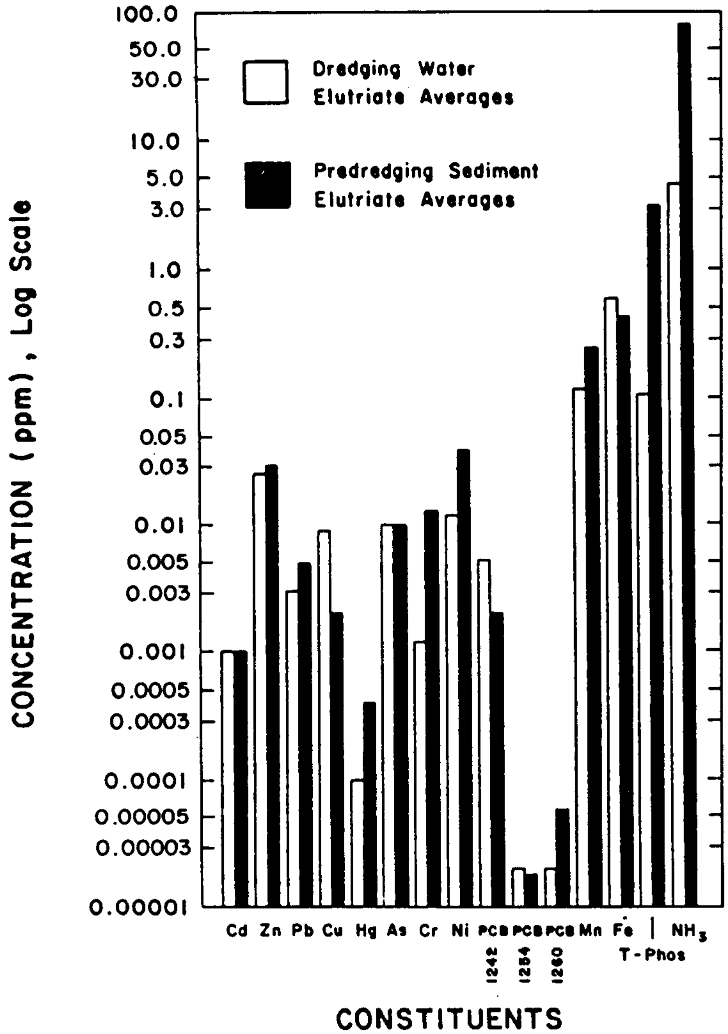

Figure 2. Comparison of average dissolved chemical concentrations from elutriate testing and from dredging site water-column measurements at Black Rock Harbor

Calumet Harbor

Elutriate test samples were taken at the Calumet River on 20 August 1985, and water-column samples were taken during cutterhead dredging in approximately 27 ft of water on 22 and 23 August 1985. Figure 3 summarizes the results of chemical determinations on six water-column samples and four replicated elutriate test samples. The equal-length bars for cadmium (Cd), (Cu), chromium (Cr), nickel (Ni), and PCB indicate that the detection limit of the instrumentation was reached. The water-column zinc (Zn) concentration was greater than was predicted from the elutriate test but both zinc concentrations were within one order of magnitude. The elutriate test failed to fall

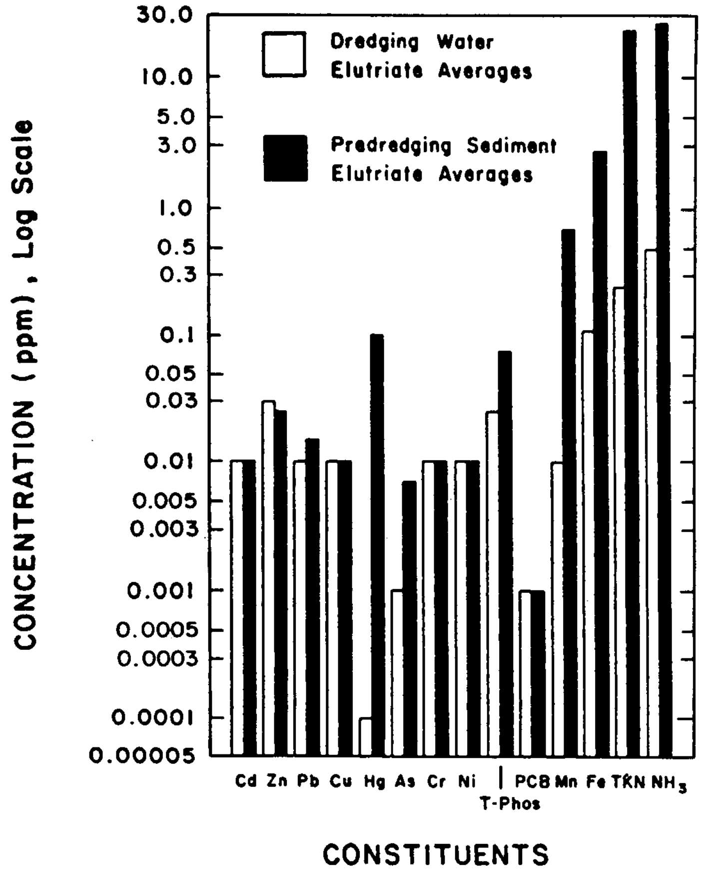

Figure 3. Comparison of average dissolved chemical concentrations from elutriate testing and from dredging site water-column measurements at Calumet River

within one order of magnitude of the water-column measurements in the cases of mercury (Hg), manganese (Mn), iron (Fe), total Kjeldahl nitrogen (TKN), and ammonia (NH_3). However, since the elutriate test values were greater than the water-column values the test was again a conservative predictor of the dredging site concentrations of these chemicals.

Duwamish Waterway

Sediment samples for elutriate testing were collected on 24 and 25 March 1984, and water-column samples during clamshell dredging were collected from a sampling position on the dredge on 26 March 1984. Figure 4 shows the average chemical concentration from the three dredging site water-column samples and averages of four replicated elutriate test samples. Water-column samples from the dredging site were higher in concentrations of Zn and lead (Pb) than was predicted from elutriate testing (Figure 4), but values were within an order

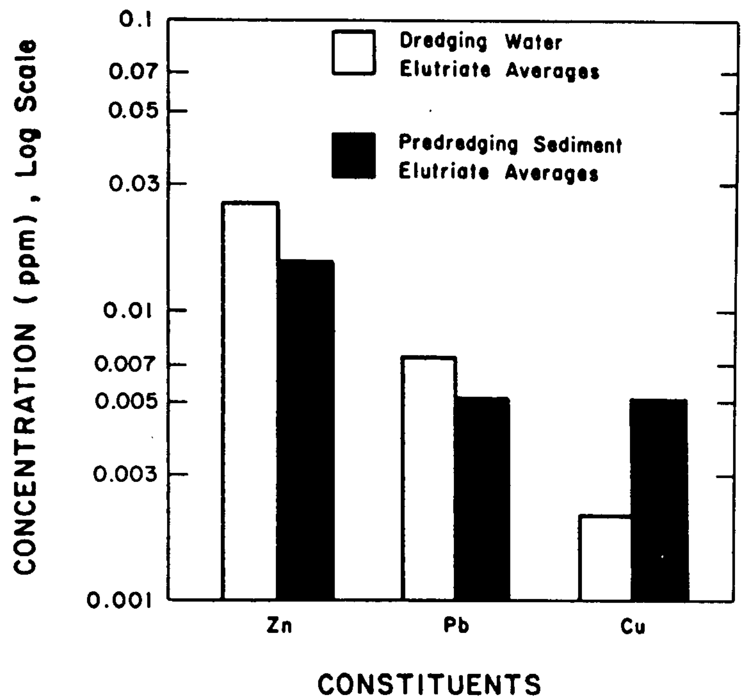

Figure 4. Comparison of average dissolved chemical concentrations from elutriate testing and from dredging site water-column measurements at the Duwamish Waterway

order of magnitude. Copper concentration at the dredging site was overestimated or conservatively predicted by the elutriate test.

James River

Bender et al. (1984) gives a detailed study of the application of the elutriate test as a predictor of dredging site chemical concentrations in the James River. The comparisons of the standard elutriate test results and chemical determinations on dredging site water-column samples (Figure 5) showed that Zn, Pb, Cu, and total phosphorus (T-Phos) were predicted within an order of magnitude and TKN predictions were more than an order of magnitude greater than the field measurements. Cadmium levels were too low to be detected in either the elutriate test water or at the dredging site.

Conclusions

The standard elutriate test was shown to predict dredging site water-column chemical concentrations, within an order of magnitude, for most chemicals in the four studies presented. Therefore, as a preliminary evaluation

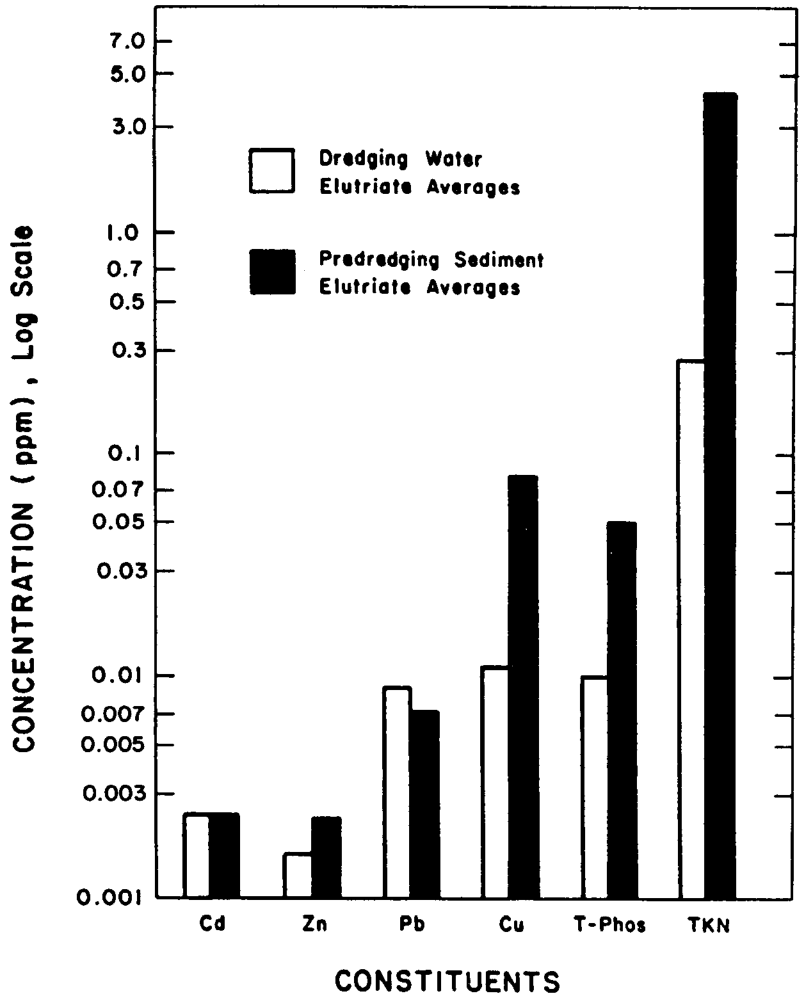

Figure 5. Comparison of average dissolved chemical concentrations from elutriate testing and from dredging site water-column measurements at the James River

the standard elutriate test is deemed worthy of further study as a predictor of dredging site water-column chemical concentrations. In some cases, however, dredging site water-column chemical concentrations were more than an order of magnitude lower than the corresponding elutriate test results. In the few cases where the standard elutriate test predicted lower chemical concentrations than were found at the dredging site, the estimates were within an order of magnitude of the dredging site water-column chemical concentrations. In general, the standard elutriate test was shown to be a conservative predictor of dredging site dissolved chemical concentrations for most of the chemicals tested.

Future Directions

Since the standard elutriate test gave reasonable predictions of dredging site water-column chemical concentrations, confidence was gained in the general applicability of the test for predictions of chemical water quality at the point of dredging. The study by Bender et al. (1984) suggested that modifying the standard elutriate test by reducing the solids-to-water ratio and reducing the mixing time could provide more reasonable results for hydrophobic chemicals and possibly TKN. Bender and his colleagues experimented in the laboratory with low solids to dredging site water ratios and with modification of mixing times to both simplify the standard elutriate test procedure and as an attempt to better simulate field TSS concentrations in the laboratory. They concluded that a shorter mixing time and smaller sediment-to-water ratio would produce more accurate elutriate test predictions for hydrophobic chemical compounds and for TKN. Phosphorus, however, was still overestimated and the modifications to the elutriate test did not significantly change the accuracy of metal concentration estimates. However, the work by Bender et al. (1984) and the general applicability of the standard elutriate test for predicting chemical water quality at high sediment concentrations suggest that modifications to the solids-to-water ratio for simulating expected dredging site conditions should be investigated to achieve more accurate predictions.

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be removed from the area. For storage capacity considerations, both surface and interstitial water must be removed from the site to allow evaporative drying and subsequent reduction in required storage volume for the dredged material. The most cost-effective management practices used to achieve these goals include creation of a smooth, gently sloping dredged material surface by careful selection of dredge discharge points, periodic lowering of the weir crest elevation to allow continued drainage, surface trenching to facilitate movement of water to the outflow structure, and removal of dried surface material from within the site (Palermo, Montgomery, and Poindexter 1978; Headquarters, US Army Corps of Engineers 1986).

During implementation of the management activities at any dredged material disposal site, numerous tasks are undertaken inside the disposal area. Most of these tasks require mobility within the site for such activities as surveying and reconnaissance, trenching, and earthmoving. To assist in these tasks, several types of equipment are routinely used in CE disposal facilities, but most of the equipment is limited in its performance. Some equipment is amphibious and can be used in the sites only when the dredged material is in a fluid state. Other equipment can begin operations in the sites at various stages of dredged material drying (after some amount of crust has formed). The major problem is that there is a period of time between the fluid stage and the formation of sufficient crust during which none of the presently available equipment is mobile in the disposal sites. There is a need for equipment capable of performing work functions during this critical period of time when trenching operations and other activities need to begin or continue.

Low-ground-pressure rubber-tired vehicles have been recently introduced which may facilitate operations within disposal areas. Because of the interest of various CE Districts in the newly developed vehicles and because of claims by manufacturers that this equipment can operate in all environments from fluid to solid, the US Army Engineer Waterways Experiment Station (WES) conducted field evaluations of the equipment in use in several CE Districts. Evaluations were conducted in Mobile, Norfolk, Philadelphia, and Savannah Districts. In the Mobile District, an ARDCO six-wheeled vehicle was evaluated, while a GEMCO four-wheeled vehicle was tested in the other three Districts.

Equipment Evaluation Procedures

During field evaluations, data on the equipment, the equipment operation and performance, and the soils were collected. Pertinent data on the equipment included weight, horsepower, number of tires, and vehicle ground contact pressure. Operation and performance data included speed of movement across the disposal site, linear feet of ditching accomplished per hour, and size of the trench formed (which indicates rate of production in quantity of material removed per hour). Soils data collected included soil strength as recorded by the hand-held cone penetrometer, shown in operation in Figure 1. Results of the field evaluations are discussed in following sections.

To evaluate the potential for equipment mobility in a dredged material disposal site, field data on soil strength must be collected. These data included the cone index (CI) and remolding index (RI), from which the rating

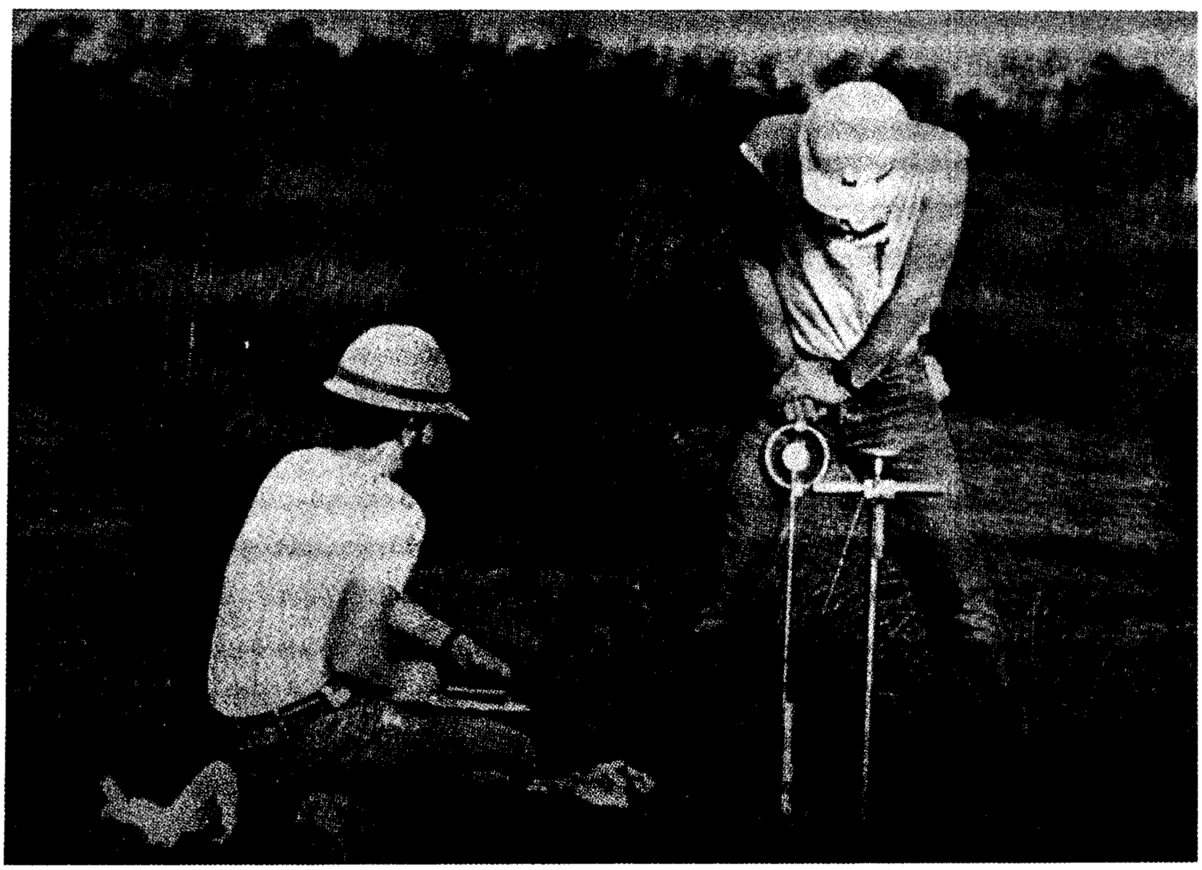

Figure 1. Field soil testing for vehicle mobility determination using the cone penetrometer

cone index (RCI) is calculated. The RCI gives an indication of the strength of the soil. The vehicle data is used to calculate a vehicle cone index (VCI), which indicates soil strength required to support the vehicle. Two values of VCI are usually determined: VCI_1 for reconnaissance operations (one pass of the equipment over an area) and VCI_{50} for trenching and earthmoving (multiple passes of the equipment over a particular area). By comparing the actual soil strength (as reflected in the RCI) to the soil strength required to support the vehicle (as reflected in the VCI), one can determine whether the vehicle can operate within a given disposal site. The operation and performance data can be used to determine the productivity of the trenching operation. This allows direct comparison of various pieces of equipment when operated under the same field conditions. In the following paragraphs the results from the field evaluations are presented for each field site and comparisons are made among field sites.

Definitions

The following definitions as presented by Willoughby (1977) are provided to assist the reader:

Cone index (CI): index of the shearing resistance of a medium obtained with a cone penetrometer. The value obtained represents the vertical resistance of the medium to penetration at 6 ft/min of a 30-deg cone of 0.5-sq in. base or projected area. The value, although usually considered dimensionless, actually denotes pounds of force on the handle divided by the area of the cone base in square inches (i.e., pounds per square inch).

Critical layer: layer of soil most pertinent to establishing relations between soil strength and vehicle performance. For 50-pass performance in fine-grained soils and poorly drained sands with fines, it is usually the 6- to 12-in. layer; however, it varies with weight and type of vehicle and with soil strength profile. For one-pass performance, it is usually closer to the surface.

Mobility index (MI): dimensionless number used to estimate the vehicle cone index, which results from a consideration of certain vehicle characteristics.

Rating cone index (RCI): product of the remolding index and the average of the measured in situ cone index for the same layer of soil. The index is valid only for fine-grained soils and poorly drained sands with fines.

Remolding index (RI): ratio that expresses the proportion of original strength of a medium that will be retained after traffic of a moving vehicle. The ratio is determined from CI measurements made before and after remolding a 6-in.-long sample using special apparatus.

Vehicle cone index (VCI): the minimum soil strength in the critical soil layer in terms of RCI for fine-grained soils and CI for coarse-grained soils required for a number of passes of a vehicle, usually 1 or 50 passes. As the values of VCI decrease, the go-no go performance capability of the vehicle increases.

VCI_1: experimentally determined minimum CI or RCI of the critical layer required for a vehicle to complete one pass. The one-pass critical layer for most vehicles is usually the 0- to 6-in. layer, except in dredged material deposits where the critical layer is often the 6- to 12-in. layer.

VCI_{50}: experimentally determined minimum RCI of the critical layer required for a vehicle to complete 50 passes in a fine-grained soil. VCI_{50} is computed for a given vehicle by first calculating an MI from selected vehicle characteristics and then converting the MI to VCI_{50} by means of a curve or table.

Drawbar pull: amount of sustained towing force a self-propelled vehicle can produce at its drawbar under given test conditions.

Mobile District Field Evaluations

Field evaluations were conducted in the Mobile District from May 4-6, 1987. These evaluations were conducted in conjunction with contract trenching operations in the Triple Barrel disposal area in Pascagoula, MS. The site is located just west of Ingalls Shipyard near US Highway 90.

The Triple Barrel disposal site is composed of three separate cells. At the time of field evaluations, only the two western cells were being trenched (shown in Figure 2); the third cell had passed the fluid stage but did not have sufficient surface crust to permit vehicle mobility. Therefore, performance data were collected in only the two western cells. Together, the two western cells measure 1,200 ft wide by 2,400 ft long and are separated by a 4-ft-high cross-dike. Each of the cells has one weir structure for drainage of surface water. The majority of the material in the containment areas is

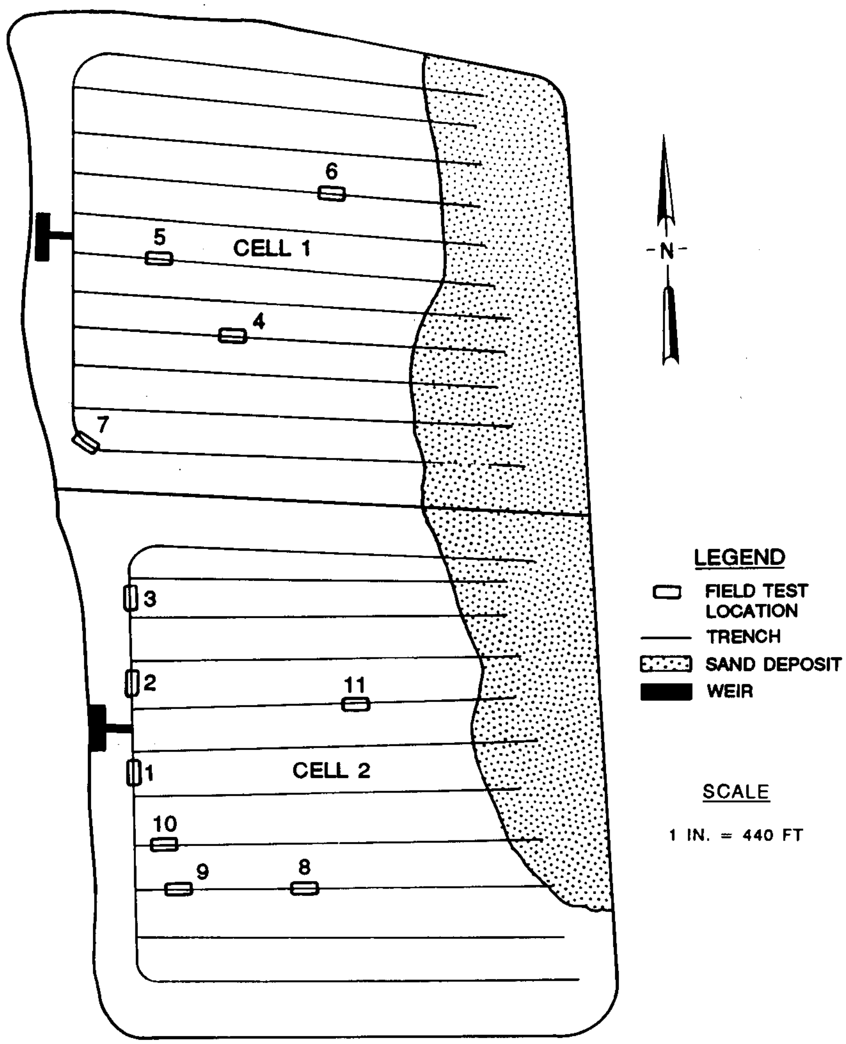

Figure 2. Triple Barrel dredged material disposal site, Pascagoula, MS

sandy clay and silty clay. The thickness of dredged material deposit varies from 8 to 9 ft. Along the eastern dikes of cells 1 and 2 is a large area of sand; the sand extends approximately 100 to 150 ft from the dike into the disposal site. The sand was deposited on the eastern side of the disposal site because that had been the location of the inflow pipeline. The area of sand is shown as the shaded area in Figure 2.

The equipment tested at Triple Barrel was an ARDCO "K" 6x6 rubber-tired vehicle which pulled a Dondi 95 ditcher (shown operating in Figure 3). The equipment is owned and operated by ARDCO of Houston, TX. The ARDCO has 113 hp and weighs 22,100 lb; it has a vehicle ground contact pressure of 1/64 psi. A tracked marsh buggy was kept on standby at the disposal site to pull the ARDCO

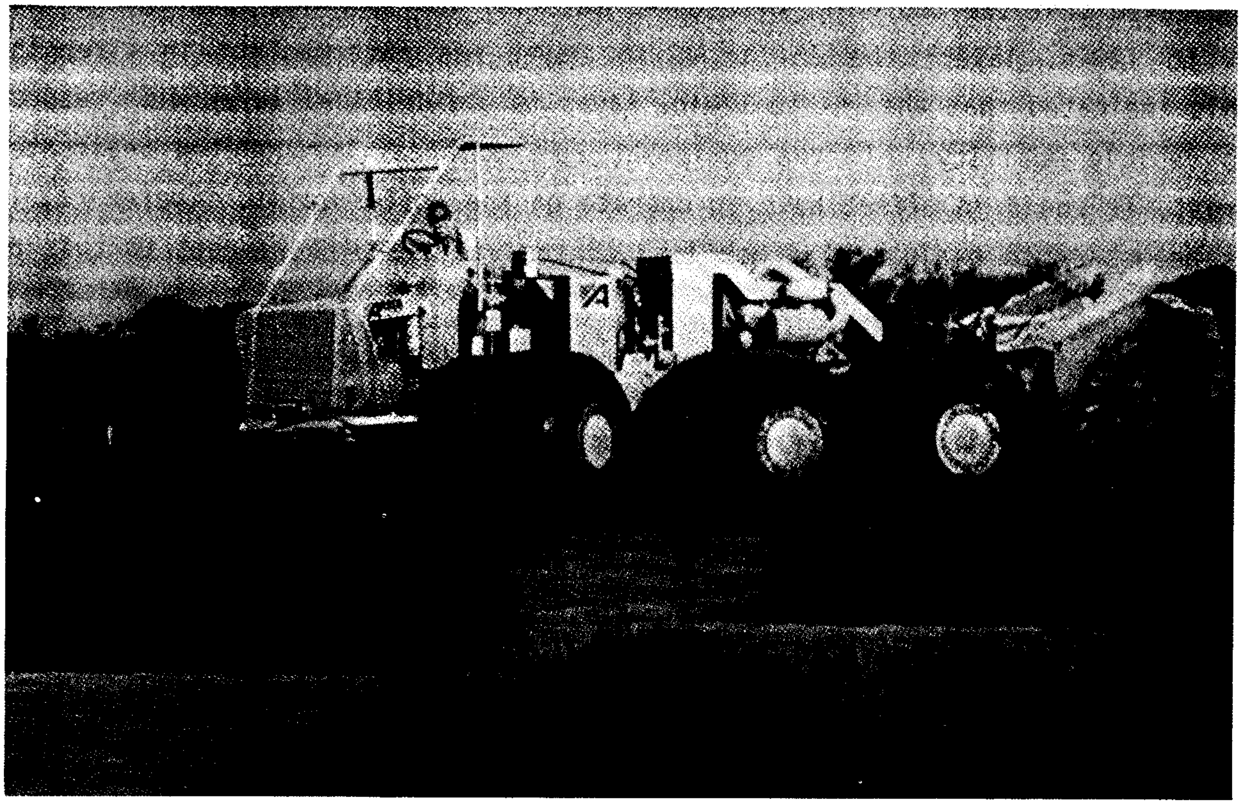

Figure 3. Rubber-tired ARDCO vehicle with Dondi ditcher raised between trenching operations in Triple Barrel disposal site

vehicle through soft sections, if necessary. The vehicle cone index (VCI) of this vehicle was determined to be 7 for reconnaissance (one pass of the equipment); the VCI_{50} for multiple passes over the same area was 18.

The surface of the two cells tested had a very thin crust which thickened slightly toward the sand deposit. The surface of cell 1 was almost barren, while cell 2 had a covering of short grasses along with some taller grass. Eleven tests were conducted in the two cells. In the southwest corner of cell 1, the rubber-tired vehicle used at this site created ruts while ditching which were about 6 in. deep; the soil in this location was so soft and wet that the ditch side slopes collapsed. In the southwest corner of cell 2, the vehicle became immobilized and had to be pulled out of the soft area. The soil in the southwest corner was softer and wetter than in the surrounding areas. Throughout most of the area as trenching occurred, water flowed quickly into the trenches, indicating the immediate value of the trenches in dewatering the dredged material.

The data collected at the Triple Barrel disposal site (Table 1) indicated that the top 6 in. of dredged material was somewhat stiffer than the 6- to 12-in. layer; the 12- to 18-in. layer was intermediate in strength. This indicated that the 6- to 12-in. layer is the critical layer with respect to vehicle mobility. If the equipment were to break through the desiccated crust, it would in effect have to operate on the softer soils. Therefore, it is necessary to evaluate the mobility of the vehicle with respect to this 6- to 12-in. layer.

Since the critical depth for the Triple Barrel disposal site was the 6- to 12-in. depth, comparison of the RCI and the VCI for that layer provides information on the expected mobility within the site of the ARDCO vehicle. The RCI of the 6- to 12-in. layer varies from 6 to 28; the VCI for the ARDCO vehicle is 7 for one pass and 18 for multiple passes. Analysis of these data indicate that the vehicle should be able to make one pass across most of the site, although at two of the testing sites a value of RCI was obtained that was below the required value of 7. Three other testing locations had RCI values that were marginally above the required value, indicating somewhat questionable mobility. These predictions (which were made in this case after the fact) were substantiated by field performance. Across most of the site, the ARDCO was able to make one pass with no problem; in several areas within cells 1 and 2, the vehicle made relatively deep (up to 6 in.) ruts which indicated that the equipment was marginally mobile; and in one location, the vehicle bogged down and had to be pulled out.

Norfolk District Field Evaluations

From June 10-12, 1987, field equipment evaluations were conducted in the Craney Island disposal facility, which is located in Portsmouth, VA, near the confluence of the James and Elizabeth Rivers. This facility encompasses approximately 2,500 acres and is divided into three compartments (Figure 4) so that dredged material disposal can be rotated annually among the cells, allowing two years of drying to occur between disposal operations in each cell. Each cell has two large weir structures on the western side, and material has typically been pumped into the site along the east side. The material in Craney Island is composed of fine-grained silts and clays with some sand; the deposit is approximately 40 ft thick. Since material was being pumped into the south cell and the center cell was still fairly soft, all tests were

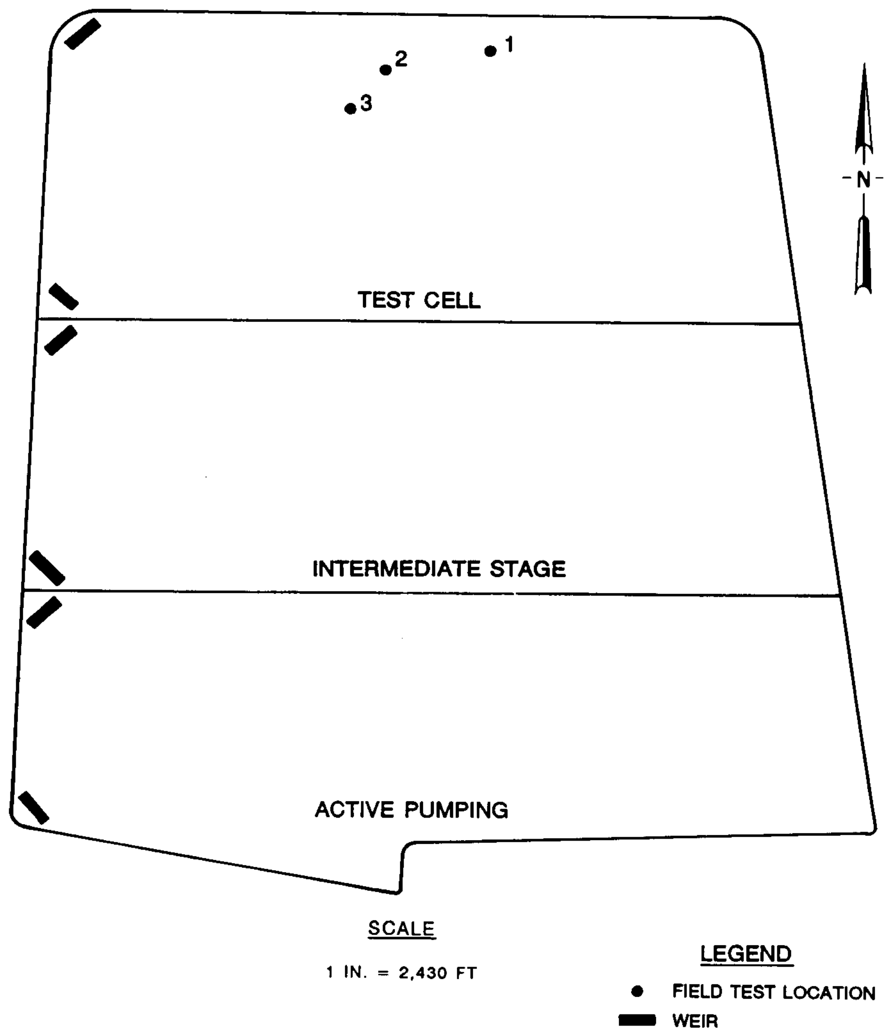

Figure 4. Craney Island dredged material disposal area, Portsmouth, VA

performed in the north cell where trenching operations were being conducted.

The equipment evaluated at Craney Island was a GEMCO GT-150 4x4 rubber-tired vehicle, pulling a Dondi 75 ditcher. This vehicle is owned and operated by the Norfolk District. This GEMCO has 135 hp and weighs 14,440 lb. The vehicle ground contact pressure is 1.6 psi. The vehicle cone index for reconnaissance (VCI_1) for this vehicle was determined to be 7, while the VCI_{50} for multiple passes was 19.

Because management practices had been implemented in the north cell during the previous fiscal year, the surface of the dredged material was dry and significant crust had formed. Therefore, the trenching equipment had no mobility problems except in one or two localized places near the site perimeter. Only sparse vegetation was present across the Craney Island disposal facility.

Field tests were conducted at three locations in the north cell of Craney Island. During the trenching operations, no flow of water into the trench was observed in most locations throughout the cell. Only in the western end of the site was appreciable water flow into the trench noticed (Figure 5). This occurred, most likely, because material is deposited on the

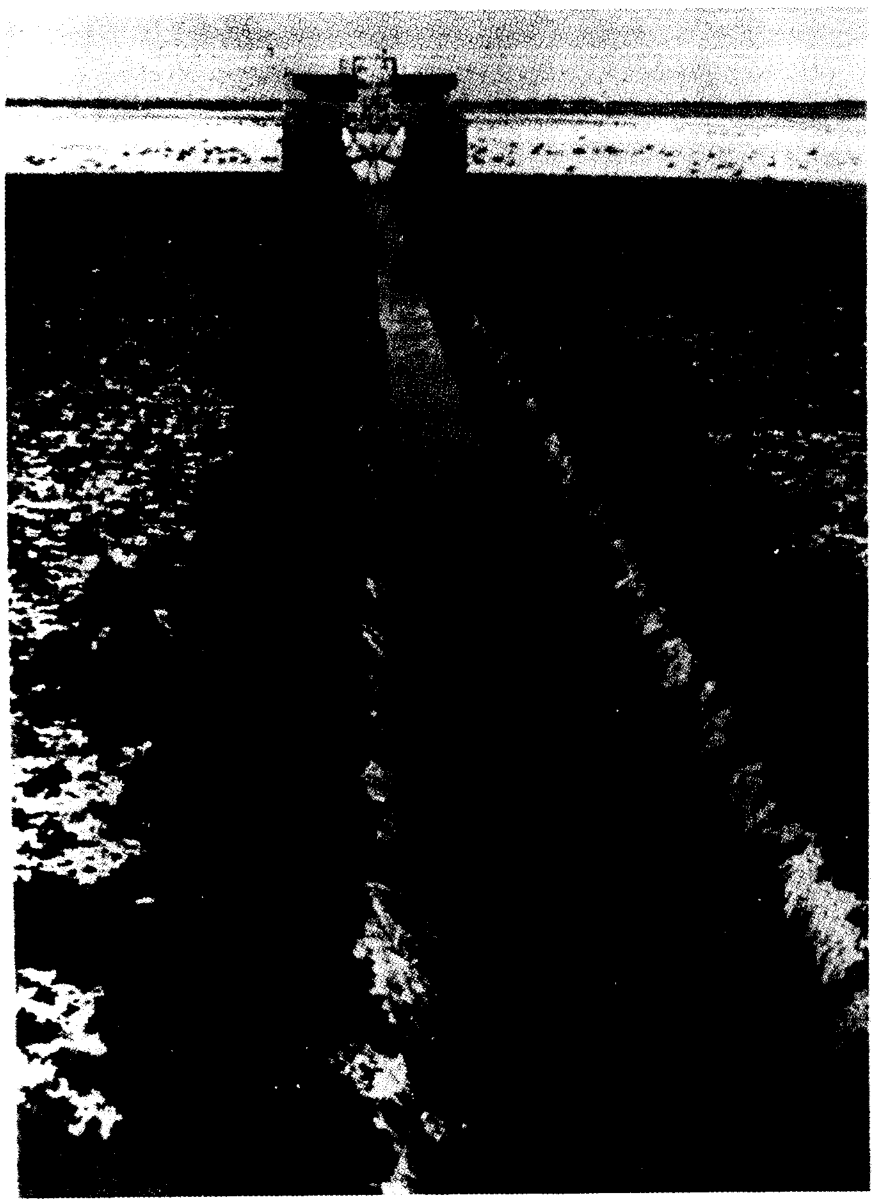

Figure 5. Trench created by GEMCO vehicle with Dondi ditcher at Craney Island; note water which immediately flowed into trench

eastern end, so the western end is at a lower elevation and contains the very fine-grained material which drains very slowly.

The data collected at Craney Island (Table 2) indicated that the dredged material generally increased in strength with depth. This is the situation usually found in regular soil deposits. Therefore, the critical depth for mobility considerations is the 0- to 6-in. layer. Comparison of the VCIs for this vehicle (VCI_1 = 7 and VCI_{50} = 19) with the RCI of the soil for the 0- to 6-in. layer (Table 2) predicted that the vehicle should be able to operate throughout the site, assuming that the test locations were indicative of conditions across the site. Since the vehicle had no mobility problems near the test locations or throughout most of the site, the prediction is considered good.

Philadelphia District Field Evaluations

The Artificial Island disposal area was the location of field equipment evaluations on June 15-17, 1987. The disposal site, located approximately 60 miles southwest of Philadelphia, is compartmentalized into three separate cells by interior dikes. Figure 6 is a map of the Artificial Island site. Each cell has one weir for water drainage. The dredged material in Artificial Island is predominantly sandy clay. No specific information was available on the thickness of the dredged material deposit in this site. All three cells were covered with a thick growth of *Phragmites* which had to be removed by bulldozing before trenching could begin to prevent entanglement of the vegetation in the rotary ditching device (Figure 7).

The equipment used at the Artificial Island site consisted of a GEMCO GT-300 which pulled a Dondi 95 ditcher. The vehicle and ditcher are owned and operated by the Philadelphia District. Vehicle data and performance information are presented in Table 3.

There was no distinguishable surface crust in the Artificial Island site. The entire deposit had dried fairly uniformly, allowing the vehicle to operate without the need for a definite crust. In addition, the roots and stalks of *Phragmites* provided a working mat which provided additional (reserve) support. The roots present throughout the subsurface caused some problems with obtaining cone penetrometer readings. Field evaluations were conducted in six locations within the center cell. In tests 5 and 6, two

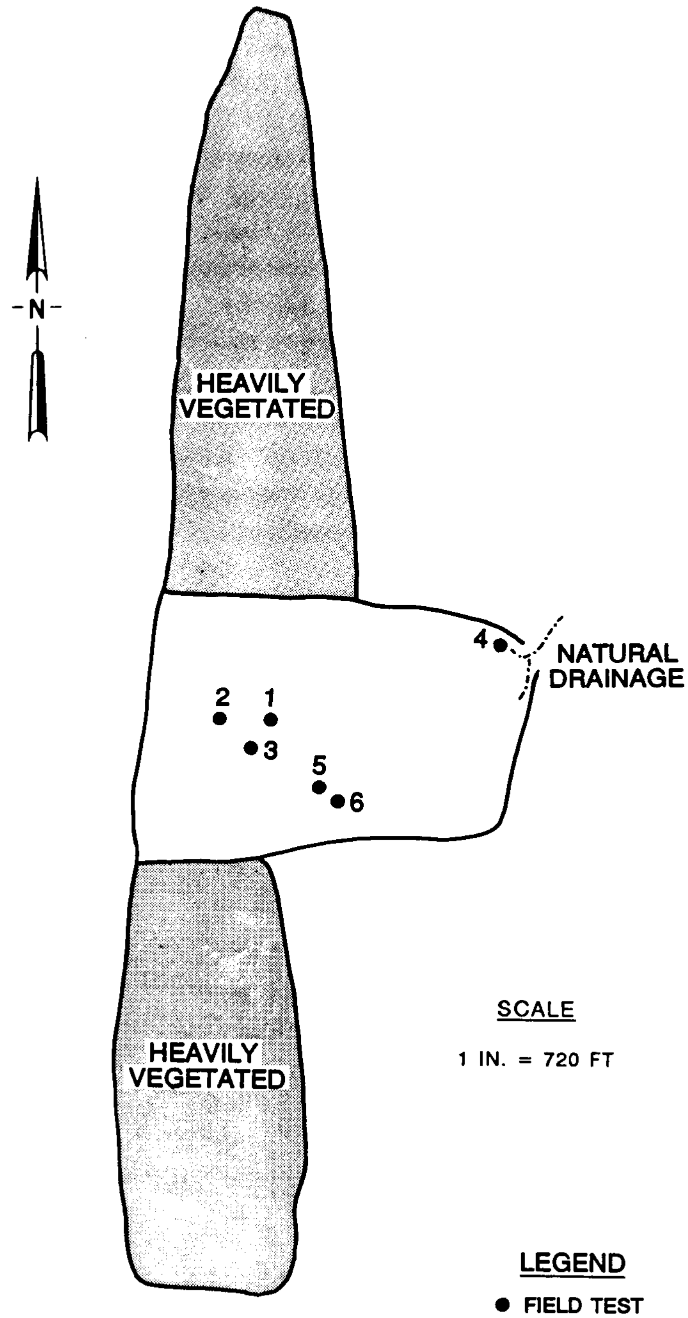

Figure 6. Artificial Island dredged material disposal area, Salem, NJ

Figure 7. GEMCO vehicle with Dondi ditcher being lowered into position for trenching

trenching passes were made. The second pass deepened the trench created by the first pass. During operation, the vehicle created ruts approximately 3 ft deep. In test 4, the vehicle was ditching in wet, relatively soft material. Because of adhesion and caking of this material between the tire treads, the vehicle lost traction and had to be assisted by the bulldozer; therefore, no time data were collected. The bulldozer is used primarily for earthmoving operations and vegetation removal, but its secondary use is assisting any vehicle which becomes immobilized.

Comparing the VCI_1 of 9 and the VCI_{50} of 23 with the RCI of the various test locations indicates that the vehicle should be able to make one pass across the Artificial Island site with little or no problem. However, mobility problems may occur if multiple passes were made in many areas.

Savannah District Field Evaluations

Equipment evaluations were conducted in the Savannah District's Disposal Area 12 (Figure 8) April 21-23, 1987. This site is located north of Savannah

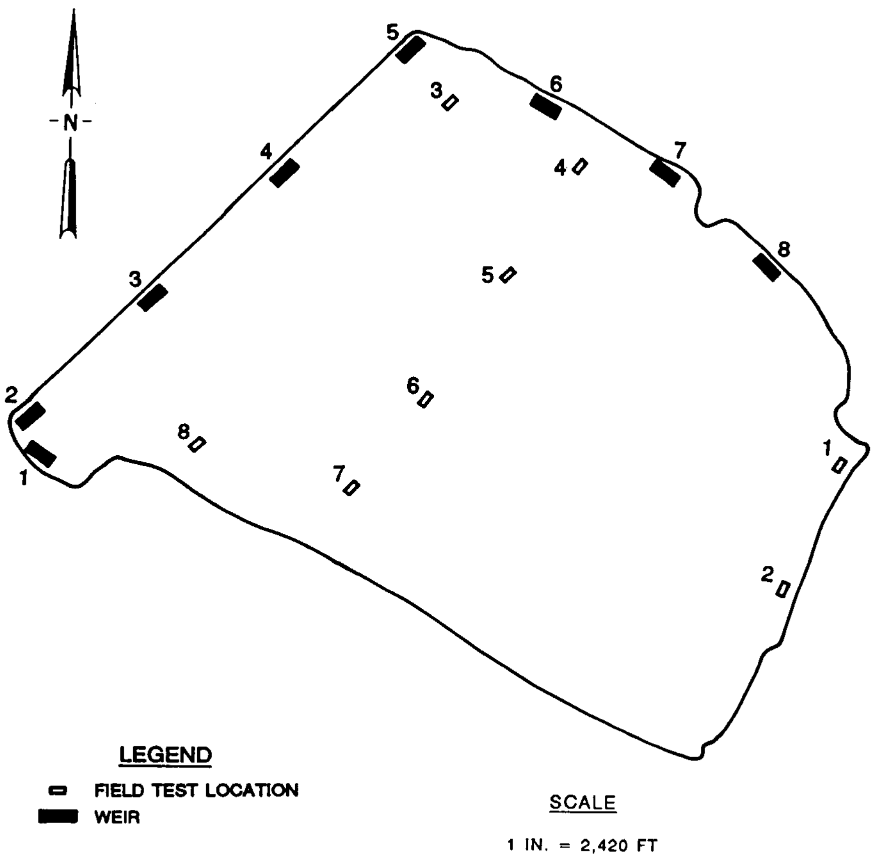

Figure 8. Disposal Area 12, Savannah, GA

adjacent to the Back River. Disposal Area 12 is one of several individual disposal sites (cells) located within one large diked containment area which is approximately 1 mile wide by 2 miles long, with the long axis being parallel to the Back River. Weirs were located along the north and west dikes at approximately 2,000-ft intervals. Fine-grained materials (mainly clays) are the prevalent material contained in these sites, although some sands and silts are present.

The equipment used at the Savannah District site was a GEMCO GT-150 and it pulled a Dondi 75 ditcher. This equipment is owned and operated by the Chatham County Department of Mosquito Control, the organization that routinely trenches disposal areas for the Savannah District. As shown in Figure 9, the vehicle can cross old trenches as necessary. The vehicle has been extensively modified to reduce the number of breakdowns previously experienced. The horsepower has been increased from 150 to about 175 by installing fuel injectors in the engine. The axles on the vehicle were upgraded by installing

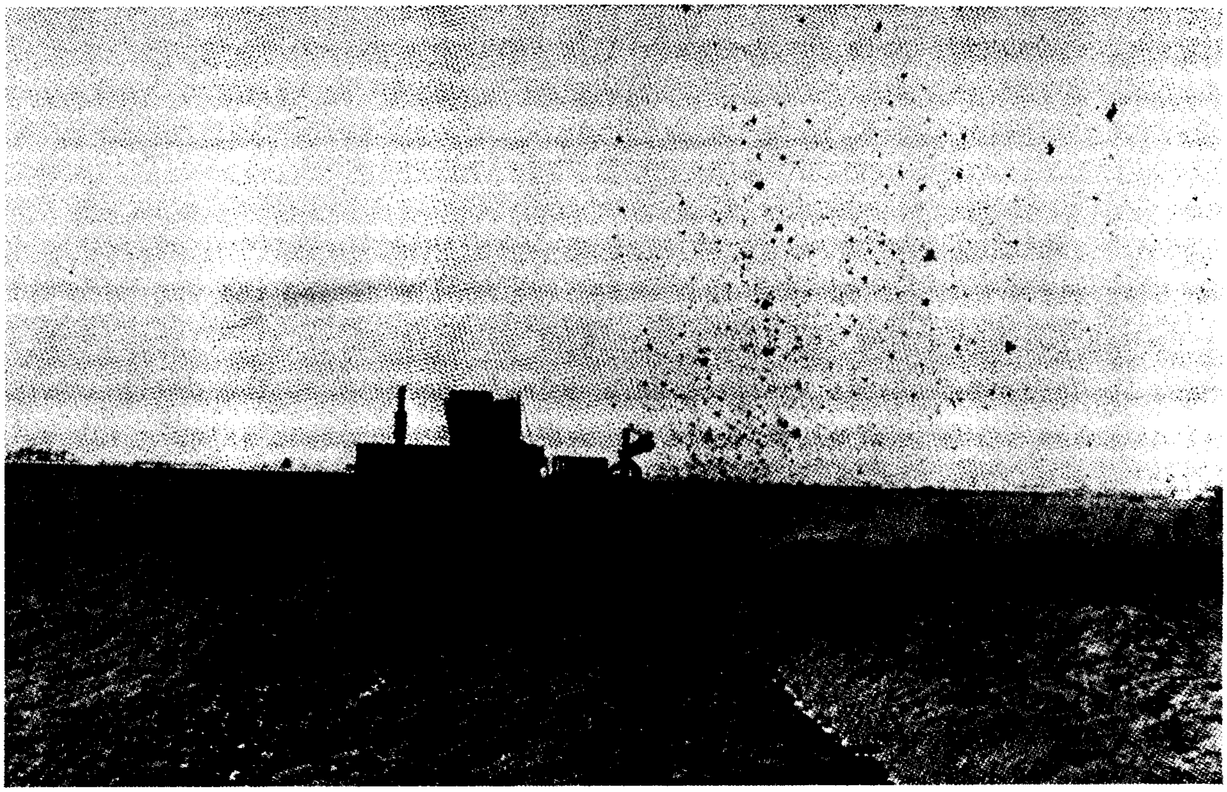

Figure 9. GEMCO vehicle crossing old ditch while trenching

Rockwell differentials. All hydraulic and oil hoses and coolers were replaced by larger and more efficient ones.

The top 6 in. of material in Disposal Area 12 consisted of a hard baked crust. The material from 6 to 18 in. was somewhat softer; at about 18 in., the material was very soft and had the consistency of axle grease. Field evaluations were conducted at eight locations in Disposal Area 12. The vehicle became immobilized at the eighth site, so no performance data were collected there. At some of the test locations the crust was so hard that a remolding index of 300+ was recorded (Table 4).

At all test sites except site 8, the vehicle was timed to provide performance information. Testing at site 8 was conducted after the vehicle became immobilized so that the RCI could be calculated for comparison to the VCI. Data collected at this site proves that a vehicle cannot operate on a site where the VCI is greater than the RCI. Comparison of the VCI_1 of 7 and the VCI_{50} of 18 with the soil's RCI indicates that at most locations within Disposal Area 12 the vehicle should be able to operate (either single or multiple passes) without problems, as long as the surface crust remains intact.

In some areas, the ability of the 6- to 12-in. layer of soil to support the equipment is questionable for even a single pass.

Vehicle Performance Comparison

All vehicles evaluated in this study were able to perform successfully when adequate crust was present, but none were mobile during the entire critical period between fluid and solid phases of dredged material. These rubber-tired, low-ground-pressure vehicles were able to operate at the dredged material disposal sites earlier than most conventional equipment (Figure 10). It should be noted that some low-ground-pressure tracked vehicles were not only mobile in the areas where the rubber-tired vehicles had mobility problems, but were used to tow immobilized equipment. The greatest problem with immobilization of either the ARDCO or the GEMCO seems to occur when the vehicle breaks

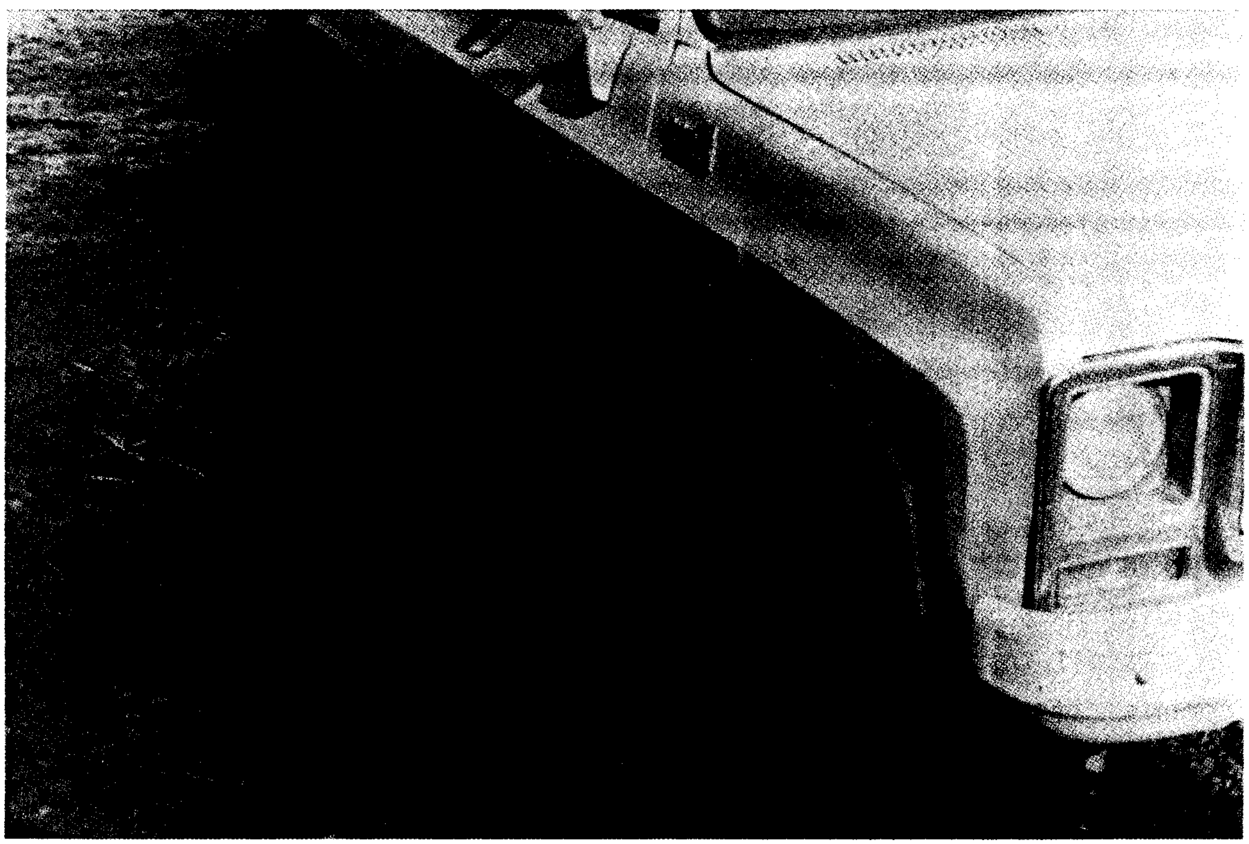

Figure 10. Corps of Engineers 4x4 vehicle immobilized where GEMCO pulling ditcher had no problem; note GEMCO treadmarks beside vehicle

through the hardened crust and the soft material below cakes between the tire treads causing a loss of traction.

The production rates for trenching varied by test site, but were relatively consistent among CE Districts. Production rates in both linear feet of ditch created per hour and cubic feet of material moved per hour are summarized in Table 5. From these data, the ARDCO and the GEMCO vehicles seem to have similar production rates. On the average, approximately 2,200 ft of trench can be created per hour and about 9,400 cu ft of material can be moved per hour.

Conclusions

The recently developed rubber-tired low-ground-pressure vehicles performed successfully in dredged material containment areas when sufficient drying had occurred to provide adequate soil support for the vehicle. The equipment could not perform trenching operations throughout the entire critical time period as dredged material changes from the fluid stage to a material sufficiently crusted to support conventional equipment. The equipment was able to begin trenching earlier than most conventional equipment, thus shortening the time during which the site is inaccessible. Based upon comparison of actual field performance and performance predictions made using field performance, the existing guidance and predictive techniques for determining equipment mobility in dredged material containment areas appears to be applicable to the new equipment. Therefore, no revision or modification of the guidance is necessary at this time.

Table 1

Triple Barrel Soil Data

Test No.*	S	Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	36	24	12	21	0.94	0.54	0.59	23	6	12
2	37	22	13	20	0.80	0.81	0.70	22	13	20
3	40	31	13	19	0.74	0.80	0.68	23	13	19
4	67	59	30	28	0.81	0.67	0.40	48	20	11
5	69	69	32	21	0.94	0.88	0.67	62	28	16
6	48	37	16	18	--	0.85	0.54	--	14	15
8	33	22	14	21	0.74	0.58	0.69	16	8	14
9	32	24	13	19	0.63	0.66	0.53	15	9	10
10	32	24	13	19	0.63	0.66	0.53	15	9	10
11	33	24	13	25	0.65	0.51	0.47	16	7	12

(Soil Evaluation)

* Location of tests shown in Figure 2.
Note: S = surface.

Table 2

Craney Island Soil Data

Test No.*	S	Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	32	47	36	38	0.58	0.61	0.65	27	22	25
2	33	37	68	82	0.72	0.62	0.56	26	42	46
3	40	54	68	59	0.46	0.65	0.50	25	44	30

(Soil Evaluation)

* Location of tests shown in Figure 4.
Note: S = surface.

Table 3

Artificial Island Soil Data

Test No.*	S	Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	64	39	55	56	0.58	0.40	0.36	23	22	20
2	43	50	70	79	0.68	0.56	0.54	34	34	43
3	20	28	43	74	0.56	0.50	0.54	16	16	40
4	22	24	84	28	0.68	0.54	0.80	16	16	23
5	44	67	75	74	0.73	0.58	0.71	49	44	23
6	--	86	--	--	0.75	--	--	64	--	--**

* Location of tests shown in Figure 6.
** On test 6 only the RCI from the 0- to 6-in. layer was obtainable due to the *Phragmites* roots.
Note: S = surface.

Table 4

Savannah District Soil Data, Disposal Area 12

Test No.*	S	Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	30	34	39	43	0.83	0.67	0.65	28	26	28
2	33	41	38	30	300+	0.77	0.63	300+	29	19
3	30	32	15	12	0.88	0.61	0.43	28	9	5
4	41	34	15	27	300+	0.60	0.40	300+	9	11
5	26	29	27	48	300+	0.66	0.58	300+	18	28
6	20	33	45	46	300+	0.65	0.68	300+	29	31
7	24	32	43	61	300+	0.80	0.39	300+	34	24
8	44	21	22	18	0.28	0.37	0.49	6	8	9

* Location of tests shown in Figure 5.
Note: S = surface.

Table 5

Vehicle Production

Site	Test No.	Minutes per 100 ft	Linear Ditching ft/hr	Material Removed cu ft/hr
Mobile	1	1.16	2,586	8,100
	2	1.07	2,804	8,781
	3	1.07	2,804	8,781
	4	1.16	2,586	10,014
	5	1.28	2,344	9,075
	6	1.24	2,419	9,368
	8	1.50	2,000	7,744
	9	1.20	2,500	9,680
	10	1.20	2,500	9,680
	11	1.57	1,911	9,806
Norfolk	1	4.25	1,412	4,015
	2	4.33	1,386	3,941
	3	4.00	1,500	4,266
Philadelphia	1	2.25	2,667	11,000
	2	2.00	3,000	11,250
	3	2.08	2,885	10,817
	5*	3.33	1,802	8,014
	6	3.77	1,591	11,273
Savannah	1	2.50	1,200	8,666
	2	1.44	2,083	15,046
	3	1.50	2,000	14,444
	4	1.54	1,948	8,778
	5	1.16	2,586	11,653
	6	1.75	1,715	7,724
	7	1.10	2,727	12,289
	8**	--	--	--

* During test 4 the vehicle became immobilized, and had to be assisted by the bulldozer; no times recorded. Tests 5 and 6 both were dual passes to deepen the ditch; therefore, the performance factors are lower than tests 1, 2, and 3.

** Vehicle became immobilized; no times recorded.

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EEDP-09-5
January 1990

Environmental Effects of Dredging Technical Notes

SELECTING EQUIPMENT FOR USE IN DREDGED MATERIAL CONTAINMENT AREAS

PURPOSE: This technical note describes methods for selecting appropriate equipment for use in dredged material containment areas. It also briefly describes the types of equipment currently being successfully used in these areas.

BACKGROUND: Management of confined upland dredged material containment areas, to dewater the material and improve its engineering properties, requires use of large equipment for activities such as surveying, trenching, and earthmoving. Because dredged material enters the containment areas as a slurry and subsequently is dried to form a stiff crust overlying softer material, its structure poses many challenges not normally encountered in conventional earthwork. Therefore, selection of equipment must be made based on not only the normal considerations for equipment selection (i.e., use, availability, and capacity), but also on dredged material site conditions. Techniques for assessing equipment mobility and performance have been developed and documented. Empirical data also can provide some initial guidance on equipment selection and timing of initial management activities.

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Introduction

Upland dredged material containment areas are being managed more intensively than ever before because of the scarcity of land for new disposal sites and expense of developing these sites as well as the scarcity of remaining storage capacity in existing sites. The purposes of managing the sites include increasing site capacity by densifying the material to be stored (i.e., removing water from the mass), improving material properties thus allowing removal and use of the material, and allowing ultimate beneficial use of the site itself (Poindexter-Rollings 1989). To meet these purposes, the dredged material must be dewatered. A number of techniques are available for dewatering and improving engineering properties of dredged material and other soft soils (Headquarters, US Army Corps of Engineers 1986; Benson 1988; Rollings, Poindexter, and Sharp 1988). All improvement techniques require construction equipment, and selection of appropriate equipment is important.

Typical Site Conditions

Sites used to contain dredged material normally pose problems not often encountered in earthwork construction. The dredged material is typically placed in a confined upland site by hydraulic pipeline dredge; the material enters the site as a slurry with a concentration of about 150 g/ℓ (which is equivalent to a dry unit weight of approximately 9 lb/cu ft). As dewatering begins through removal of ponded surface water and evaporative drying of the dredged material, a crust forms on the surface of the material. After a summer drying period of about 3 months, the crust normally has sufficient depth and strength to support a person. At this point in crust development, the crust typically has a water content of about 1.2 times the water content at the material's plastic limit ($1.2 \times PL$). The material below the crust is usually at a water content of 1.8 times the material's liquid limit ($1.8 \times LL$); the subcrust material will stay in this condition indefinitely unless the dredged material layer thickness is very small (less than 3 ft initially) thus allowing the entire thickness to dry or other methods of dewatering (besides evaporative drying) are instituted. (The Atterberg plastic limit is defined as the water content at which the soil ceases to be in a plastic state and starts to crumble. The Atterberg liquid limit is the water content at which the soil and water start to flow as a viscous liquid.) The depth to which surface crust will form depends on dredged material properties, disposal site drainage conditions, and environmental factors such as precipitation and evaporation. Typically, ultimate crust thickness in sites subjected only to evaporative drying ranges from 8 to 15 in. (Please note that ultimate crust thickness corresponds to a much greater initial thickness; for instance, an ultimate crust thickness of 8-15 in. might result from initial placement of 1 ft to several feet of slurry. Thus, a direct comparison cannot be made between initial and ultimate thicknesses.)

As seen from the preceding discussion, the stratigraphy of dredged material containment areas can be very different from that normally encountered in the field, with the strongest material on the surface and softer material below. If a disposal site has been used for multiple disposal operations, the stratigraphy of the site can be very complex. Because of these site conditions, special techniques must be used to evaluate the potential mobility of construction equipment in these areas.

Equipment Evaluation Techniques

The most quantitative evaluation technique for assessing equipment mobility in dredged material containment areas is one developed by Willoughby (1977, 1978) during the Dredged Material Research Program (DMRP). It was developed by modification of an existing NATO Reference Mobility Model (NRMM), which is a user-friendly version of the Army Mobility Model (AMM). These models evaluate soil strength with depth and use the strength of the "critical" layer to predict vehicle mobility across a soil deposit. The major modification required for application to dredged material was recognition that the critical layer, i.e. the weakest layer, is not necessarily located at the surface of the ground. This evaluation technique can be used to predict the performance of equipment used for conducting various work functions in a containment area, specifically single-pass and multiple-pass operations (Headquarters, US Army Corps of Engineers 1978).

To evaluate the potential for equipment mobility, field data on soil strength must be collected. These data include the cone index (CI) and the remolding index (RI), which are obtained by pushing a hand-held cone penetrometer into, respectively, the in-situ dredged material and a remolded (compacted) specimen of dredged material. These data are then used to calculate the rating cone index (RCI), which gives an indication of the strength of the soil. The procedures are repeated at various depths and locations throughout the containment area to provide a picture of soil strength across the entire area. These data can then be compared to data for specific pieces of equipment, which indicate soil strength required to support the vehicle. Procedures for using this equipment evaluation technique are discussed and vehicle data are given by Willoughby (1977, 1978), Green and Rula (1977), and Poindexter (1989).

Empirical Approach

At times, a District office may not have the resources available to conduct an equipment evaluation as described above, or the District may not have had experience with using equipment on dredged material and may want a very tentative indication of dredged material conditions before initiating an evaluation. In either case, some approximate correlations, or indicators of soil strength, are given in Figure 1. Since these correlations were developed for soils other than dredged material deposits and should be applied to the "critical" layer for equipment mobility considerations, it may be more useful to apply them to the subcrust dredged material. Also a very simple test can easily be conducted to give a rough indication of the soil support to be expected from the material in its present condition: a person can attempt to walk on the dredged material surface. A rule of thumb is that if a person can walk on the dredged material surface, then low-ground-pressure equipment can work on it.*

To be somewhat more quantitative, a few calculations can be made which may give an indication of the pieces of equipment that can or cannot operate on the dredged material surface at the time and dredged material condition of the empirical test. Divide the weight of the person who walked on the dredged material surface by the contact area of the sole of his/her shoe (in square inches). This will yield the ground-contact pressure of the individual which can then be compared to the manufacturer's specifications for various equipment. Any vehicle with an equal or lower ground-contact pressure can probably be used for a single-pass operation in the disposal area. Some typical values for individuals' ground-contact pressures (Rush and Rula 1967) are given in Table 1.

Several cautions must be remembered regarding this empirical approach. This approach gives a very rough indication of site conditions and thus potential vehicle mobility; it should not be used to determine when to initiate operations in a site nor to select specific pieces of equipment, but simply to provide tentative guidance on when to conduct an equipment evaluation. This approach

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* James E. Walker, July 1988, Operations Division, US Army Engineer District, Mobile, Mobile, AL.

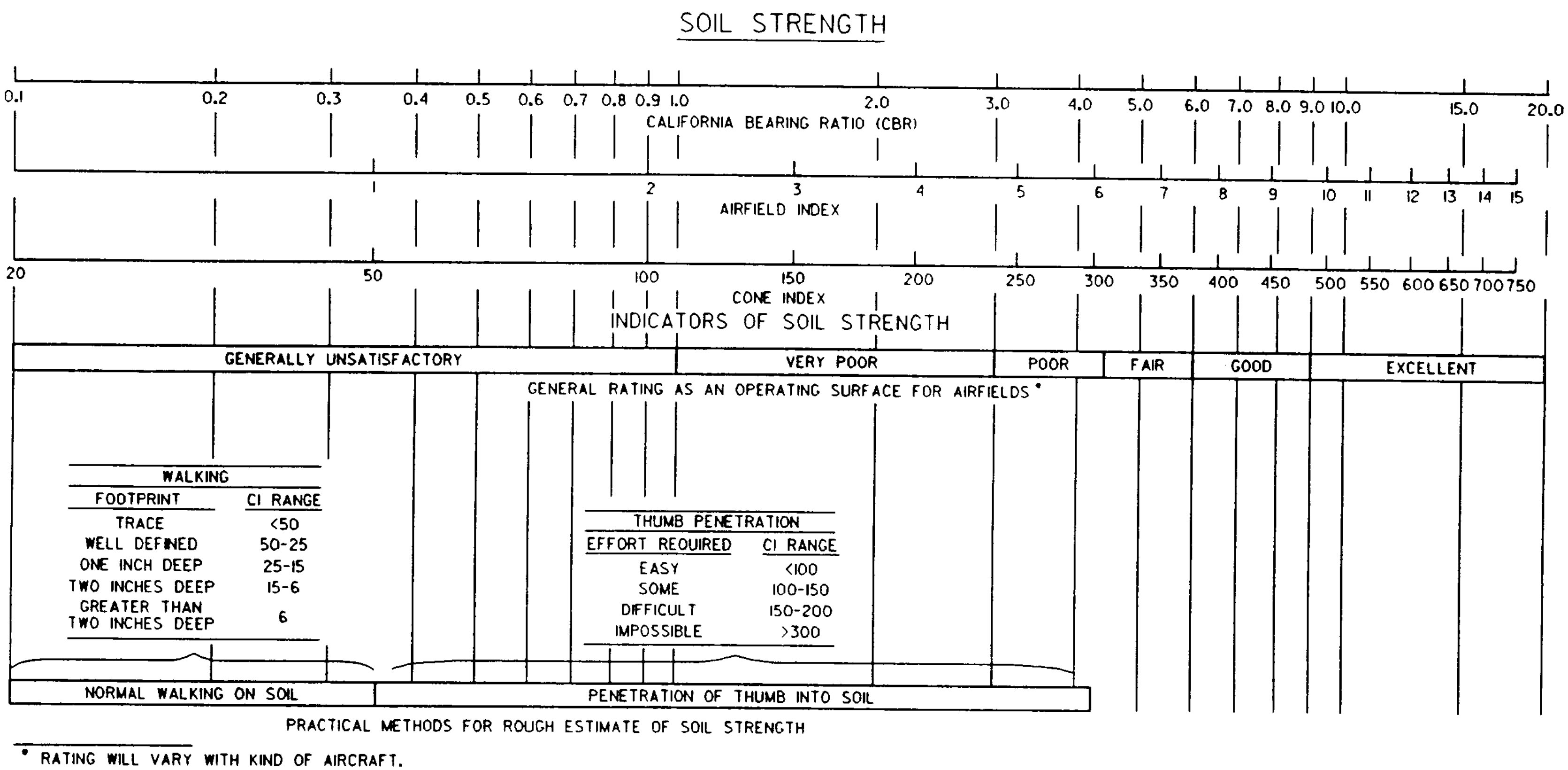

Figure 1. General correlations between soil strength and practical indicators of soil strength (modified from Hammitt and Rollings 1987)

Table 1

Examples of Ground-Contact Pressure for Individuals

Individual	Height in.	Weight lb	Area on One Footprint, sq in.	Ground Contact Pressure, psi
1	67	159	34.0	4.7
2	68	154	32.0	4.8
3	69	168	32.7	5.1
4	75	187	34.7	5.4
5	68	166	31.2	5.3
6	68	167	32.7	5.1
Average	69	167	32.9	5.1

only gives tentative guidance regarding conditions in the areas where the individual walked. Also, soft spots normally occur within a dredged material containment area (especially near the weir and in corners of the site) and may cause equipment mobility problems. This empirical test does not indicate whether a working platform, or mat, will be needed below the equipment to reduce the vehicle ground-contact pressure; additional field experience (empirical data) or the equipment evaluation technique previously described will be required. Mats are normally needed if the soil strength available is near the soil strength required to support the vehicle for its intended use. If a vehicle will be working in a stationary position or in some manner will be disturbing the soil with eccentric loadings or side-to-side movements, then mats are normally needed. If mats are needed, any type of platform may be used that can distribute the weight of the vehicle over a larger area and that is easy to place and move in the containment site. The following materials have been successfully used as a working platform in dredged material containment areas: timber or log rafts, landing mat, and 3/4-in. marine plywood (for an expendable mat).

Equipment Used by Districts

The equipment used in dredged material containment areas is usually low-ground-pressure construction equipment. Typical vehicles used during dredged material dewatering activities include draglines, backhoes, bulldozers, mini-excavators, and trenchers (such as Ardco or Gemco). Draglines are often used to dig perimeter trenches in the containment area while working from the perimeter retaining dike or a berm inside the dike. Backhoes and mini-excavators are used to dig trenches throughout the site or to clear trench intersections. Bulldozers are initially used to spread material placed by draglines on the inside of dikes during perimeter trench construction; they are later used to windrow dewatered material for removal from the containment area. The trenchers are used to pull rotary ditchers (such as Donde) to create trenches throughout the disposal site. Examples of equipment working in dredged material containment areas are shown in Figures 2 through 5.

After dredged material has dried, the dewatered material is often scraped from the surface of the deposit and is removed from the site for various beneficial uses. The equipment mentioned above is then supplemented with scrapers and possibly larger hydraulic excavators. Dry material is normally windrowed before removal by a scraper, as shown in Figure 6.

Figure 2. Dragline working from berm to create perimeter trench and sump near weir (courtesy of Charleston District)

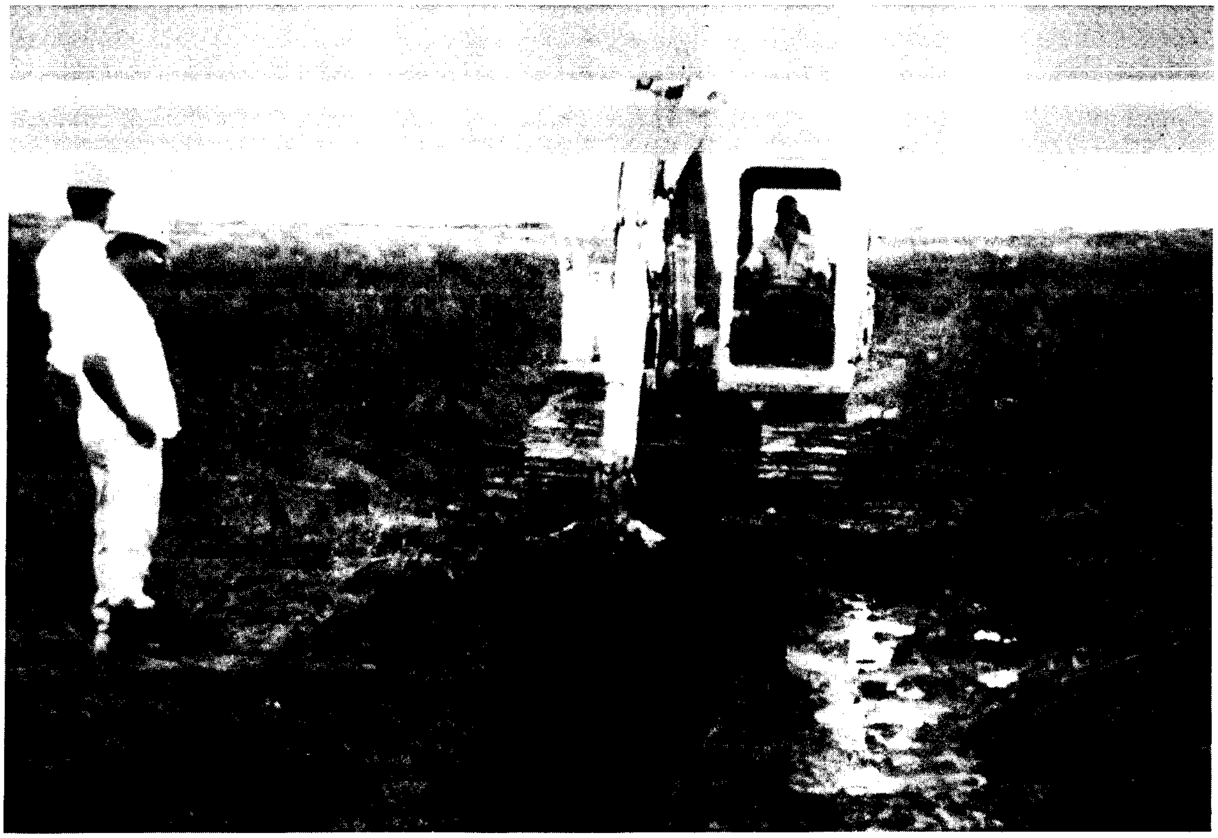

Figure 3. Mini-excavator operating on wooden mats to dig interior trench; notice the trapezoidal bucket (courtesy of Mobile District)

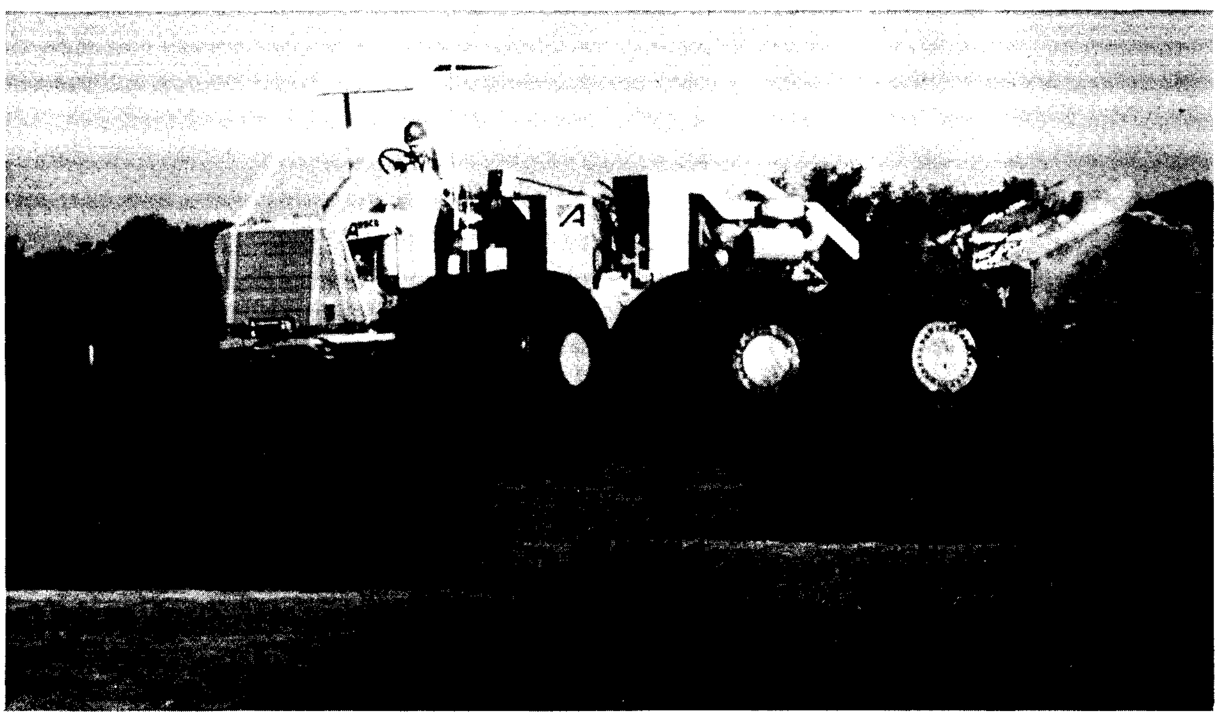

Figure 4. Trencher with rotary ditcher lifted between trenching operations

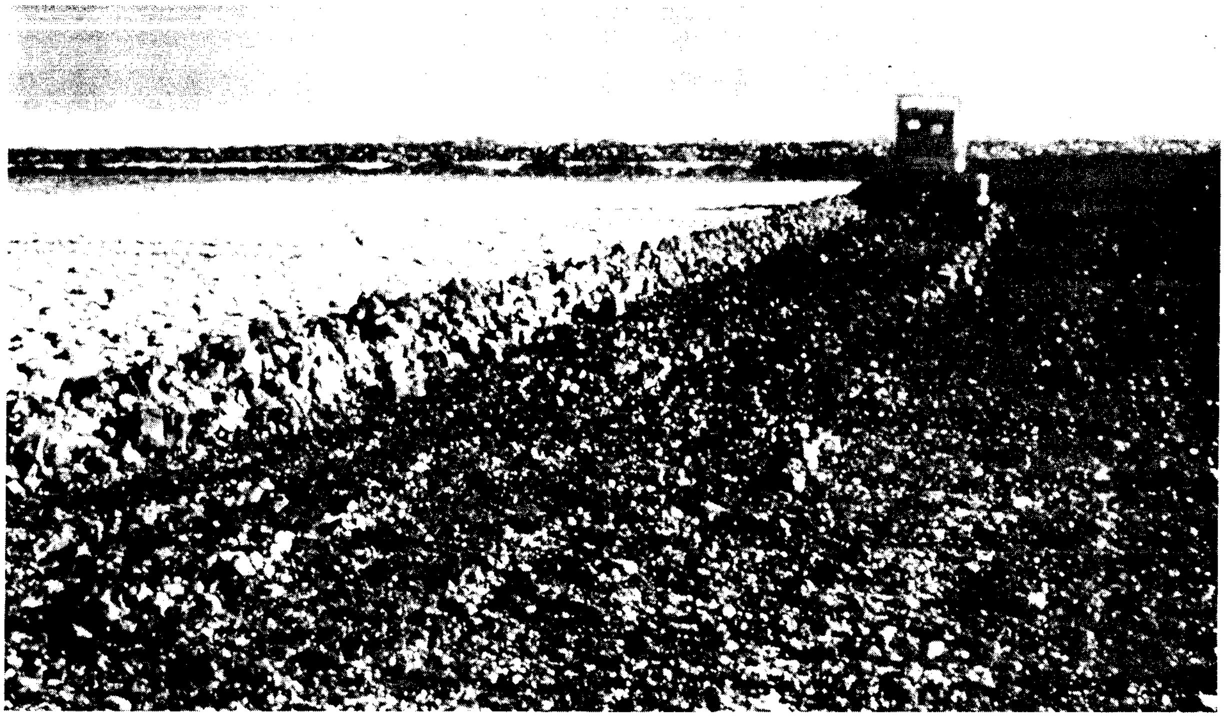

Figure 5. Bulldozer scraping dried material from the dredged material surface (courtesy of Charleston District)

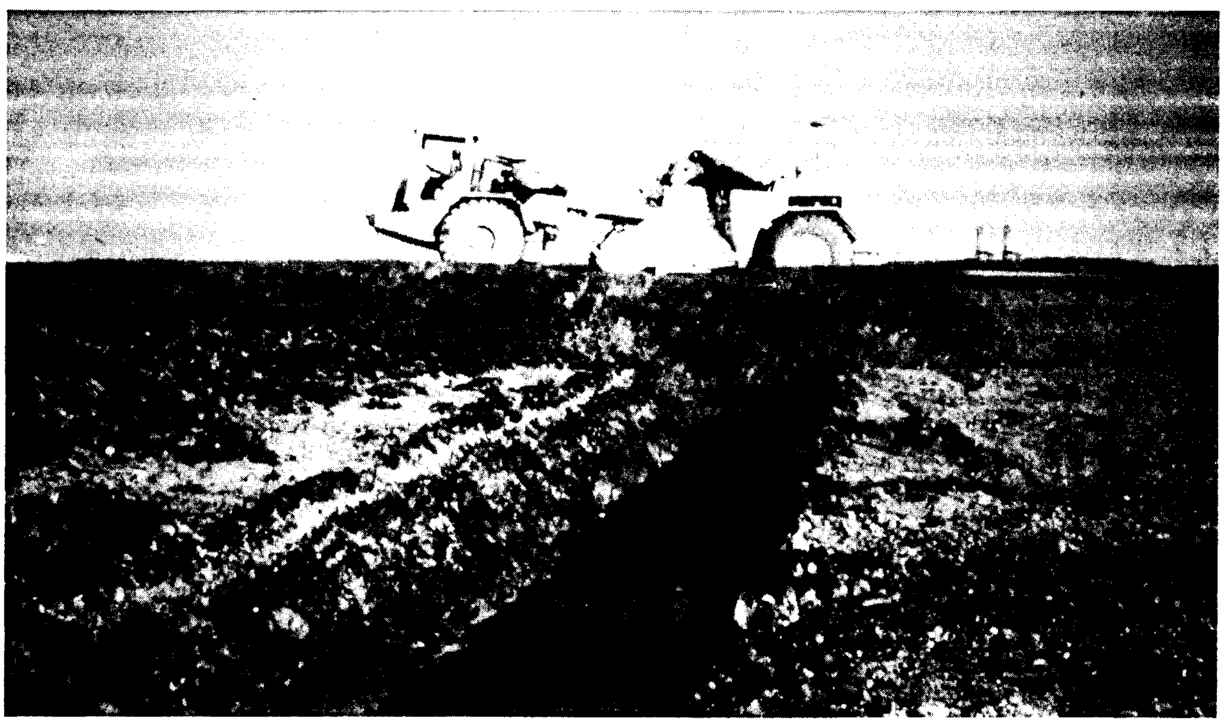

Figure 6. Scrapers removing dewatered and windrowed material from the site for dike improvement (courtesy of Charleston District)

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December 1990

Environmental Effects of Dredging Technical Notes

Alternative Dredging Equipment and Operational Methods to Minimize Sea Turtle Mortalities

Purpose

This technical note provides guidance on dredging and management alternatives for channel dredging projects to minimize adverse effects on sea turtles.

Background

Certain coastal channels are known to have high sea turtle densities. These turtles potentially can be adversely affected when these channels require dredging. However, operational practices and equipment modifications can be implemented to minimize injury to and mortality of these unique animals. Sea turtle mortalities from dredging operations have been dramatically reduced since the first reported incidents at Cape Canaveral ship channel in 1980.

The sea turtle species potentially affected by dredging are loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and Kemp's ridley (*Lepidochelys kempi*). All three species are listed on the Federal Threatened and Endangered Species List. Kemp's ridley is of additional concern since its numbers have had a precipitous decline over the past forty years. Because of their population status, mitigation or compensation for their loss is generally not acceptable by National Marine Fisheries Service under the Endangered Species Act.

Additional Information or Questions

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seek refuge at the Cape Canaveral entrance channel, especially during the winter (Butler, Nelson, and Henwood 1987). The Canaveral channel is also unique in that it contains one of the largest known aggregations of subadult loggerhead turtles in the world (Richardson 1990).

The activities of sea turtles in aquatic habitats are virtually unknown, particularly for ship channel habitats. Sea turtles are found in channels year-round, but appear to be more abundant in the warmer months. While turtles have been observed in channel areas along the Gulf Coast and East Coast of the United States, the highest concentrations are found in Florida. Mortalities or injuries of sea turtles from dredging have been documented primarily in only two channels--Cape Canaveral Harbor, Florida, and King's Bay, Georgia. These incidents appear to occur only on hopper dredges, since no incidents have been reported for other types of dredges. The lack of reported impacts on turtles in channels other than King's Bay and Cape Canaveral has been attributed to the lack of turtle monitoring during dredging and to the lack of an observed impact in other channels.

However, this could also be as a result of a lack of turtle occurrences in the channels during the time of dredging.

Other aspects of sea turtle life history are important to their management in channels. Kemp's ridleys, which have declined from tens of thousands to a few hundred, are on the verge of extinction (Fontaine and others 1985). Any further loss of this species may jeopardize its existence. Loggerheads and green turtles have much larger population numbers. Estimating their absolute abundance, however, is hampered by their oceanic existence. The age at which female turtles first nest is estimated to be between 15 and 30 years (Nelson 1988). Female adults deserve the greatest degree of protection since they take such a long time to mature and are the reproductive base of the population. Females should be protected especially in the spring and summer, when eggs are laid.

History of Dredging Effects on Sea Turtles

Before the 1980 maintenance dredging of the Cape Canaveral, Florida, entrance channel, sea turtle mortalities were not an issue during dredging operations. During the 1980 maintenance dredging of the Cape Canaveral entrance channel, an unusually large number of sea turtles were discovered in the channel and sea turtle mortalities from dredging activities were also documented.* The presence of large numbers of sea turtles in the channel was reported by shrimpers who had incidentally trawled up the turtles in a torpid condition during the two unusually cold winters prior to the 1980 maintenance dredging (Joyce 1982). Most of the turtles were loggerheads, but greens and Kemp's ridleys were also found.

A Sea Turtle/Dredging Task Force was formally established by the US Army Engineer District, Jacksonville in May 1981 to address the issues of sea turtle mortalities from dredges and maintaining a navigable channel for commercial interests and national defense. The task force is comprised of representatives from the NMFS, US Fish and Wildlife Service, Florida Department of Natural Resources, US Navy, university representatives, and the US Army Corps of Engineers. As a result of alternative dredging equipment, operations, and management techniques recommended by the task force and others, the documented numbers of turtles affected by dredging at Cape Canaveral entrance channel have been reduced from 71 in 1980 to 3 in 1981, 9 in 1984, 5 in 1986, 28 in 1988, and 7 in 1989. The 1988 channel maintenance removed the largest number of cubic yards of dredged material (approximately 1.5 million cu yd) since 1980 and had a much lower estimated turtle mortality than 1980.

The incidental take of sea turtles during dredging operations has been documented in the Cape Canaveral ship channel since the first study conducted in 1980 and King's Bay, Georgia, ship channel since its construction in 1988. During the ten-year dredging period from 1980 to 1990, 149 incidents with three species of sea turtle (loggerhead, green, and Kemp's ridley) have been reported from Cape

* P. W. Raymond. 1980. "Marine Turtle Observations aboard Dredge *Long Island*, Port Canaveral, Florida, 19 July - 1 August 1980," unpublished report to the National Marine Fisheries Service, St. Petersburg, FL.

Canaveral and King's Bay entrance channels. This included 123 incidents at Canaveral and 26 incidents in King's Bay channel. Reported incidents have been limited to hopper dredges.

Table 1 shows the documented incidence of sea turtle mortalities since the 1980 dredging at Cape Canaveral entrance channel. The overall apparent reduction in sea turtle incidents may have been attributed to the alternative equipment tested and changes in operational procedures during dredging projects. The fluctuations in numbers of incidents may also be a reflection of seasonal and annual fluctuations in the sea turtle populations.

Table 1

Reported Sea Turtle Entrainment Incidents by Species during Dredging Activities from 1980 to 1990

Year	*Caretta caretta*	*Chelonia mydas*	Unidentified*	Total
		Cape Canaveral Entrance Channel, Florida		
1980	50	3	18	71
1981	1	1	1	3
1984/85	3	0	6	9
1986	5	0	0	5
1988	8	2	18	28
1989/90	0	6	1	7
Totals	67	12	44	123
		King's Bay Entrance Channel, Georgia/Florida		
1987/88**	7	1	1	9
1988	3	0	2	7†
1989	9	0	1	10
Totals	19	1	4	26

*Fragments of sea turtle carcasses not identified to species. It is assumed that most are *Caretta caretta*.

**Initial construction dredging for Trident submarine base.

†This number includes two *Lepidochelys kempi* caught in 1988 at King's Bay, Georgia.

The physical properties of the channels that attract the turtles to these habitat are also unknown. The channels were "created" by dredging and thus may not be considered natural habitats. The channels have water depths greater than the surrounding areas to accommodate ship traffic. The channels vary in depth from

12 to 50 ft and have substrates that vary from sand to silt to mud. Data on the physical properties of the channels have not been examined to see if relationships with turtle presence or absence can be established.

Because sea turtles are pelagic and very mobile, little is known about their life history once they leave a nesting beach. Most information about their activities in the Canaveral channel and other channels is based on hypotheses with very little data to substantiate or disclaim them. Time and space density patterns of turtles in the channels are unknown. Data are difficult to obtain in Canaveral Channel because the water is turbid and the bottom has a suspended, flocculent silt layer 6 ft or more deep. The turtles may be in the channel for various reasons. The presence of an abundant food supply may be attracting them. They may migrate into the area from cooler northern weather conditions. Sea turtles have been found covered with mud in a dormant state (Carr, Ogren, and McVea 1980). They may bury in the mud of the channel to cleanse their exteriors of parasites or for protection against colder environmental conditions. How the turtles are impinged by the dredge is also unclear. However, it appears that the turtles which are on or in the bottom are run over by the draghead and then sucked up into the hopper. Examination of flow patterns around the draghead suggests that it is unlikely a turtle will be sucked in from the sides unless it is very close.

Summary of Dredging Alternatives and Modifications

Operation Modification

Seasonal Restriction. Restricting dredging to a season when turtles are least abundant or least likely to be affected was one of many alternatives that has been implemented. The NMFS designated September through November as the best time for dredging based on the turtle's seasonal density trends and the presence of gravid females during the summer nesting season (Henwood 1990). The winter months were excluded due to the presence of higher numbers of turtles migrating into the area from colder more northern climates. In addition, the cooler water temperatures during the winter months may cause turtles to be in a more inactive state and more susceptible to impacts. The spring and summer months were excluded because this is the breeding and nesting season for turtles and protecting nesting females is a high priority. Kemp's ridleys are present during the late winter and early spring.

Draghead Pumps Turned Off. An additional operational procedure implemented in 1985 was the turning off of the pumps when the dragarm was raised and lowered. This was to reduce the potential of entraining turtles in the water column as the draghead was being raised or lowered.

Reduced Vessel Speed. During the 1989-1990 maintenance dredging at Cape Canaveral with the *McFarland,* the dredge operating speed was reduced from 2-3 knots to approximately 1 knot. Although the reduction in the speed of operation may potentially provide more time for a turtle to react to the oncoming draghead, its effectiveness relies on the animal's ability to respond to the oncoming

[redacted]

occasions and did not result in any documented turtle mortalities. However, the required dredging depth could not be achieved. A hydraulic pipeline dredge is another potential option that may be used in the Canaveral Channel. However, the operation of the pipeline dredge will be limited to seasons when the sea conditions are calmer (Hrabovsky 1990). The relatively slow dredging motion of clamshell and pipeline dredges would likely further reduce turtle mortalities. The ability of these dredge types to provide the required depth in a timely fashion and at a cost comparable to other methods has been studied, but use of these dredge types does not appear to be economically or logistically feasible.

If the effects on sea turtles are time dependent, that is, longer dredging time results in more turtles being affected, then dredging by the most efficient means would reduce mortalities. Using larger hopper dredges and more dredges would shorten the time period of the dredge in the channel. This potential management alternative requires further investigation.

Draghead Type

Changing the type of draghead used on the hopper dredge may have been the most effective operational change used for reducing turtle mortalities. An IHC draghead was used during the Canaveral maintenance dredging in 1980, but subsequent dredging used the California-style draghead. The design and upright positioning of the IHC draghead causes its suction opening to act like a scoop, while the California-style draghead sits level in the sediment and may be less likely to entrain turtles (Studt 1987).

The number of potential variables (that is, dredge size, speed, and temporal differences) makes equipment difficult to evaluate. In addition, turtle mortalities were not effectively evaluated because screen sampling techniques were not consistent throughout. Dredging operation procedures should be considered when evaluating the types of dragheads versus numbers of turtles killed. Comparisons of dragheads alone cannot be validly used without evaluations of the methods and procedures used to operate each draghead. These procedures differ among ships and personnel.

The intake grating of the draghead was reduced to 12-in. openings from 1980 to 1987. However, it was decided in 1988 that reducing the size of the opening in the draghead probably did not reduce turtle mortalities. In addition, reducing the size of the grate openings attached to the bottom of the draghead may affect the ability to assess the number of turtles taken since turtles impacted by the draghead may be prevented from entering the hopper and not counted by observers.

Deflectors for Draghead

Rigid Deflector Design. A "cow-catcher" type turtle deflector was installed on the draghead and tested on the Corp's dredge *McFarland* in 1981. The deflector was constructed using 1/2-in. steel plate in a V-shape and attached in front of the draghead with 2-in. anchor chain. The deflector was designed to pivot with the movement of the draghead. This deflector was crushed in a matter of minutes.

In 1988, two new conceptual designs for deflectors were selected for testing during the Cape Canaveral maintenance dredging. One design was for a rigid deflector made of steel plates welded to the front of the draghead in a parallel V-shape pattern. Plates 1/2 in. thick were spaced 10 in. apart and varied in height from 24 to 43 in. high. The bottoms of the plates were 6 in. below the horizontal plane of the draghead when dredging at the 46-ft depth. This deflector was rendered inoperable due to the loss of plates within 3 days of its initial use. During this test two turtles were impinged between the plates of the deflector, resulting in their death.

Flexible Deflector Design. The second deflector tested during the 1988 Canaveral dredging was constructed of flexible 1/2-in. chain webbing forward of the draghead. This deflector was attached in a V-shaped configuration to the dragarm and draghead. A solid steel 12-in.-diameter shaft (ball) was installed at the lower forward end of the "V" to help the chain webbing maintain its shape in front of the draghead. This flexible deflector maintained its integrity during the one-week test and subsequent three weeks of dredging. One small turtle was taken by the dredge during 4 weeks of dredging. This turtle was small enough to fit through the chain webbing which may have contributed to its not being deflected. This flexible deflector showed promise of being effective in excluding turtles from the dredge. It maintained its integrity with a minimum of repair and did not affect production of the dredge.

The US Army Engineer Waterways Experiment Station (WES) Environmental Laboratory and Hydraulics Laboratory and the NMFS Mississippi Laboratory conducted tests of the deflector cooperatively in Panama City, Florida, during April 1989 on the *McFarland*. The objective of the tests was to monitor the area of suction influence around the draghead and the action of the flexible turtle deflector using divers and underwater video cameras. As a result of these tests, modified designs for the flexible turtle deflector were developed.

This modified flexible chain webbing turtle deflector was installed on both dragarms of the *McFarland* during the 1989-1990 maintenance dredging at Cape Canaveral, Florida, entrance channel. Installation of the deflectors and inflow screening was completed before dredging started. The turtle deflector tested was a flexible A-frame pipe structure designed to plow approximately 2 to 4 in. into the sediment ahead of the draghead. The heart of the system consisted of a solid steel shaft 10 in. in diameter and 4 ft long, which weighed approximately 1,000 lb and was attached by a cable sling noosed around the drag suction pipe. Attached by 1-in. shackles to the front of the steel bar were two triple-strength steel pipes forming the side legs of the bottom A-frame. Cross support braces made out of

4-in. triple-strength (schedule 120) pipe connected the side pipes to the solid support bar in the aft position. The side chain mesh was formed using 1/2-in. high test steel chain welded and bolted together to form the meshwork with 12-in. square openings. The side legs of the A-frame were attached to horizontal support plates welded to the draghead just above the heel pad on each side.

In order to deflect turtles, the deflector is required to ride on the ocean bottom. If the device is suspended in the water column, it will not deflect turtles to the side and would still allow turtles to go under the draghead. Since the deflector is attached to the dragarm, the positioning of the deflector is dependent on the angle of the dragarm. The turtle deflector was designed to work while the draghead was operating on the ocean bottom at a depth of 40 ft or less. If the draghead operates below the necessary 40-ft depth, the deflector would be pulled upward and off the ocean bottom.

The deflectors tested during the 1989-1990 Canaveral maintenance dredging required frequent repairs and were, therefore, ineffective for the duration of the dredging project. After observing the repeated destruction of the turtle deflectors, it was determined that the strength of future deflectors would need to be greatly increased.

Additional testing of the flexible turtle deflector design was done with draghead models at the Scripps Institute of Oceanography in San Diego, California. Numerous variations of deflector designs were tested under different conditions and evaluated according to efficiency in deflecting ability. The deflector models were attached to a plexiglass California-style draghead model. Underwater video photography was used to document the flow of material around the deflector devices and into the draghead to evaluate the deflector effectiveness.

Deflector tests investigated the ability to physically deflect the simulated (scaled 1/8) turtles out of the path of the dredge. Figure 1 shows the design which most effectively deflected the simulated turtles and best conformed to the sediment bottom. The sides of this design had a combination of chain and a solid metal bar. In all tests, the smallest simulated turtles (representing 11-in. turtles) were the most frequently taken by the draghead. These were small enough to go under the deflector in places which were raised off the sediment bottom. More turtles were found to be taken when the deflector shape became deformed or did not continually conform to the sediment bottom. This was seen when the deflectors were tested with a contoured or rough bottom.

Figure 1 is the deflector design which has the most potential for reducing turtle mortalities from California-style suction dragheads. Deflecting efficiency for all size classes of turtles depends on whether the deflector conforms to the contour of the sediment bottom at all times during dredging. Although this design effectively follows the bottom contour, incorrect installation of the deflector onto the draghead may prevent the deflector from correctly touching the sediment bottom. In model tests, the deflectors tested at 2.72 knots did not remain in continual contact with the sediment bottom as well as those tested at 0.9 knot. Frequently,

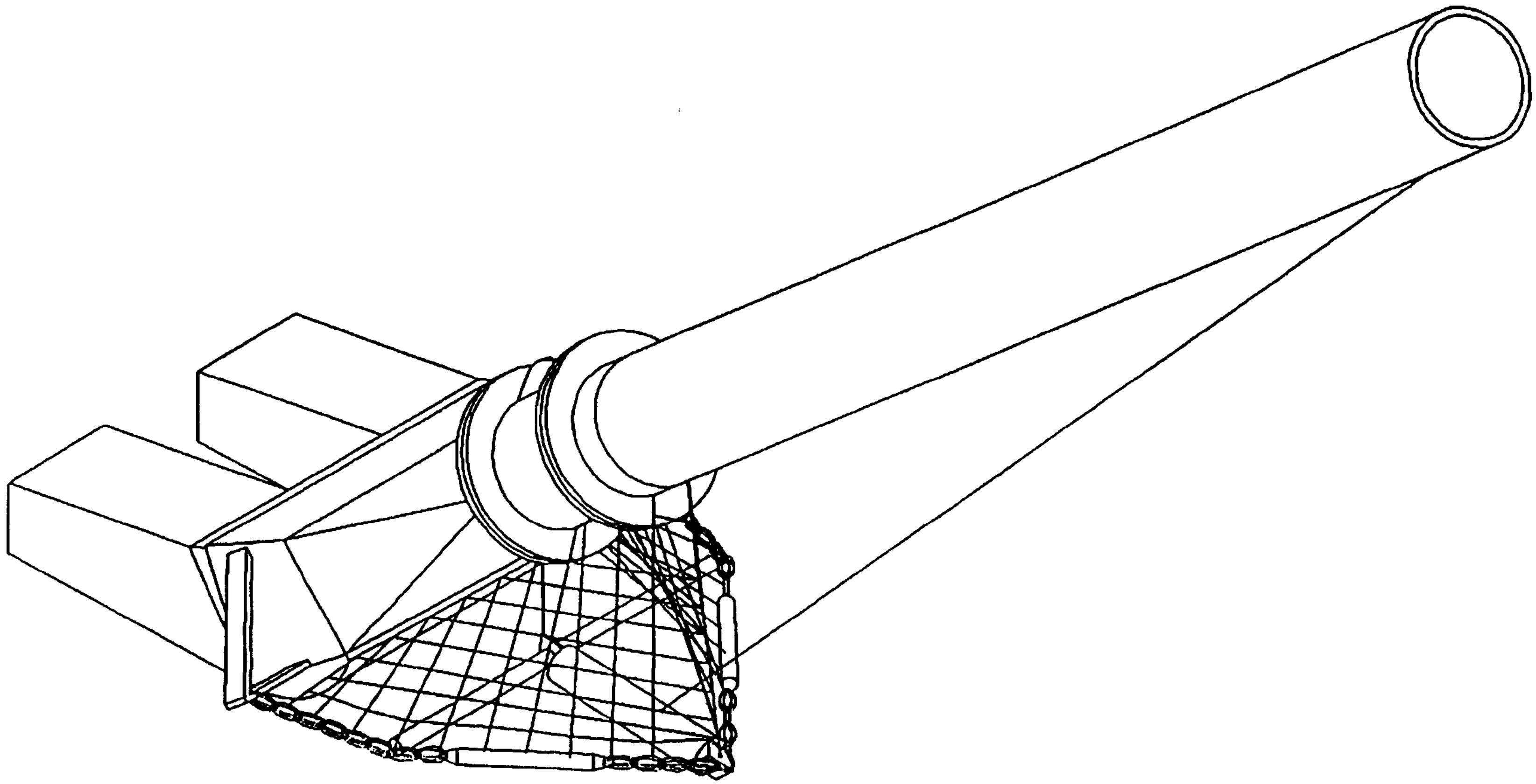

Figure 1. Deflector design having straight bottom frame sides with combined chain and bar; support cable attached to front and rear of center weight

fewer simulated turtles were deflected when the model dredge operated at 2.72 knots than at 0.9 knot. A slower operating speed may also give turtles more time to react to the deflecting device. A slower dredge operating speed and the deflector design shown in Figure 1 are suggested for testing during future hopper dredging projects in Cape Canaveral entrance channel when turtle deflectors are required.

Summary of Sea Turtle Management Alternatives

Relocating Turtles

A local shrimper was contracted during some Canaveral dredging projects to trawl ahead of the dredge to clear the channel of turtles and relocate them 5 miles down the coast to safety. However, the trawler could not work safely in front of the moving dredge because the trawler's nets would often bog down with large clay balls in the channel. This would spin the trawler around and subject it to a potential collision with the dredge. Trawling was then conducted at a greater distance ahead of the dredge. In the past, this proved to be ineffective because of the inability to move the large numbers of turtles found in the channel and those turtles which return to the channel once removed. However, recent observations suggest a decline in the number of turtles present in the channels.* Relocation of turtles out of the channel may be feasible when there are lower densities of turtles but requires additional investigation.

Although turtles may be present, trawlers cannot pull nets on the bottom inside jetties or nearshore because rocks or old pilings may snag and tear nets. Previous turtle trawling surveys were usually done from the jetties outward, which was less destructive to the nets than trawling inside.

Trawling should be done in the specific area where the dredge will be operating when it returns from the dump site. The dredge and trawler should work together to determine where the trawling should concentrate while the dredge is at the dump site. While the dredge is actually dredging, the trawler(s) could work in the surrounding areas or in an area historically known for high turtle densities.

Baiting of turtles away from the dredging site is another relocation option. It has been suggested that one reason turtles may be taken so frequently by shrimpers is that they are attracted to the fish and other bycatch which is thrown overboard. If turtles are attracted to bait, then they might be attracted away from the channel. However, whether the turtles will respond and in adequate numbers is not known.

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* A. Bolton and K. Bjorndal. 1988. "Survey of Sea Turtles in Cape Canaveral Channel," unpublished survey reports to the National Marine Fisheries Service, St. Petersburg, FL.

Dispersal of Turtles

Various techniques such as sonic pingers, tickler chains, bubblers, and electric currents have been suggested as methods to disperse turtles away from the dredging. However, it is not known if the turtles will respond to these stimuli or if the turtles can respond rapidly enough to elude a hopper dredge, particularly if the turtles are in a dormant or torpid condition.

Monitoring

Monitoring of Potential Dredging Impact

Each Corps District is required by the Endangered Species Act to conduct literature or biological surveys before every dredging project to document any endangered species occurrences in the area of dredging and determine the potential impacts related to the dredging activities. For some dredging projects, additional monitoring measures are required such as dredged material screening and endangered species observers.

Systematic trawling or aerial surveys are conducted in the channels before dredging. These surveys help determine the population status and distribution of the sea turtles in the channels over either a short or extended period of time. The information resulting from the present trawling and aerial methods is severely limited because of the behavior of the turtles and difficulty in locating the animals. These methods can only survey turtles which are in the water column or surfacing. Very little information can be collected about turtles on or in the bottom sediment, although these are the turtles most susceptible to being taken by the dredges.

Monitoring of Turtle Mortality

Endangered Species Observers. Recovery and documentation of sea turtle parts is a monitoring requirement. Accurate identification of these parts and detailed records are a vital part in the evaluation of dredging impacts and success of the turtle deflectors.

The Endangered Species Observer Program was established in 1980 and evolved through consultation between the NMFS and the US Army Corp of Engineers, as mandated by the Endangered Species Act. Endangered species observers are used during dredging projects whenever biological data suggest potential impacts on sea turtles. The observers work closely with the dredge crew to identify and record dredging incidents with endangered species. The observers hand sort all collected debris and record information on every dredging load. A reported sea turtle incident represents one sea turtle which was entrained either whole or in parts. Sampling for whole turtles and parts is done through observation and inspection of the hopper, the draghead, and screening of the intake structures or hopper overflow.

Material Screening. Because the material being pumped into the hopper dredge is a dark-colored mud-sand mixture, visually monitoring turtles taken into the hopper is difficult. To enhance the ability of observers to monitor sea turtle mortalities, screening of skimmers and overboard overflows has been required of hopper dredges in the Canaveral Channel. Because overflow screens primarily collect floating materials, estimates of turtle mortalities based on overflow screen collections may be low. In 1988, the WES Environmental Laboratory conducted tests to assess techniques for monitoring recovery of turtle parts on dredges. To obtain better estimates of sea turtle mortalities, tests were conducted on screening inflows during the 1988 dredging at Cape Canaveral. While the screening of inflows appears to be feasible, further investigations are needed to ensure their effectiveness and safe operation. The variability of internal discharge piping into the hopper inhibits a generic design to screen inflow. Additional considerations are the type of material being dredged and the safe retrieval of parts by the endangered species observers.

Monitoring the Effectiveness of the Management Program

The management program cannot be evaluated by monitoring turtle numbers or mortalities. The effectiveness of these protective measures is difficult to assess because of numerous operational differences among the 1980-1990 dredging projects. Screening of inflows may allow for more accurate assessment of turtle mortalities and the effectiveness of measures to reduce the mortalities. However, a reduction in sea turtle mortalities during dredging in the Cape Canaveral ship channel since 1980 may be attributed to dredging operational changes or possibly to a decrease in the local abundance of turtles.

This management plan can be evaluated by assessing whether the management practices used are the best available technology to reduce sea turtle mortality and injury to the least number possible. Evaluation of whether the best sea turtle life history information is being provided to implement the best management practices should also be considered. This evaluation should be conducted by a technical advisory group and recommendations provided to the agencies for implementation.

Summary and Conclusions

Substantial apparent reduction in sea turtle mortalities likely has resulted from modifications in dredging equipment and operational practices. These modifications were a result of recommendations from cooperative efforts by Federal and state agencies, universities, and the dredging industry. Another effective measure which has been implemented is the use of seasonal restrictions. Measures which are being tested and show potential for reducing turtle mortalities include the use of a flexible turtle deflector and alternative dredging equipment. The problems of dredging a flocculent silt material in high wave climates and the general lack of biological information on the turtle activities in channels make reducing turtle mortalities a difficult challenge.

A long-term requirement exists for the Corps to maintain channels for safe navigation and national defense and at the same time reduce turtle mortalities from dredging operations in channels. This can be best achieved through a long-term management plan that implements the best management practices using the best available dredging technology and sea turtle life history information.

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